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THE RELATION OF ORE-DEPOSITION TO FAULTING.*

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There are, as we all now realize, many types of ore-deposits, of diverse origin. Many are formed superficially by chemical precipitation from surface waters—this appears to be true of many important iron and manganese deposits, for example. Superficial ground waters have played an important part, especially in the modification of already formed ore-deposits, and have accomplished such changes that the final workable ore-body in many cases might not have existed were it not for their activity. This is especially true of certain copper deposits. There are still other natural methods by which workable concentrations of the metals are formed. In speaking in a general way of ore-deposits and their original relations it may be in the interest of clearness to explain that my own experience has been mainly in the Cordillera region of North America, the ore-deposits I have in mind are those of gold, silver, copper, lead, zinc, and other and rarer metals, and the origin I have in mind is the origin of the primary ore-deposits, which in many cases are fabulously rich, and in most cases are potentially workable ore; but which in some cases become commercially profitable only through secondary concentration by surface waters, as in the case of certain disseminated ores of copper.

* A lecture delivered before the Geological Club of Yale University.

It is these primary ore-deposits of the less common metals that should be kept in mind throughout the remarks to be made on the subject.

We have all of us, I suppose, at one time or another passed through the uniformitarian stage of our belief as to the origin of ore-deposits. Impressed by the classic work of Lyell with the truth that geological forces are operating around us today as they did in past ages, with the satisfying demonstrations of the glacial theory as against the theory of a catastrophic flood to explain certain drift accumulations, we were kindly disposed to explanations of ore-deposition along similar normal and well-regulated lines. Whether we believed that ores were deposited by the work of ordinary descending ground waters, with Emmons, or that they were deposited from ascending hot waters, with Posepny, ore-deposition was most easily regarded as a universal and continuous phenomenon.

But of course there arose in our minds, at first dimly and so illy formulated as to result only in the proper sceptical attitude, the inevitable question: If ore-deposition is a universal process, why do we not find ore-deposits everywhere? This question was answered satisfactorily, if temporarily, by referring to the observations of Sandberger, Becker and many others to the effect that the country rocks of certain mineral districts carry small quantities of the metals, and we comfortably argued that the circulating waters, were they hot or cold, have dissolved these disseminated metals and precipitated them in concentrated form.

Two considerations, however, finally broke the force of this argument; first, the consideration that in a mineralized district, where all the rocks have been altered and searched by mineralizing waters, it is *a priori* more probable than otherwise that the disseminated metals have been introduced by the mineralizing solutions. Second, the chemists have found that disseminated metals occur in all rocks as well as those in mining districts. Dr. Washington (as I recall his conversation with me) has told me that he has found copper, for example, in every rock analysis where he has looked for it.

So we were led gently back to our original quandary—Why, if ore-deposition is a thus uniform and continuous process, do we not find ore-deposits wherever we look for them? This the prospector and the mining engineer know not to be the case, and they oppose certain definite restrictive facts to our conception. Ore-deposits are localized without any reference to ground water or disseminated values in rocks or even hot springs. Certain broad provinces are ore-bearing, and certain others barren. Within the ore-bearing provinces certain districts are highly mineralized and certain others are barren; and within the highly mineralized districts certain openings or fissures are filled with highly metalliferous filling, certain others with barren gangue filling, and certain others have not been filled at all, although these latter have been channels for water circulation for many thousands of years.

The location by the prospector of the main ore-deposits soon established in the minds of many geologists an evident geographic connection between ore-deposits and igneous rocks. This connection was at first explained by us, retaining what shreds we could of the conservative cast of uniformitarianism, by the theory that the igneous rocks, while hot, had heated and rendered more active the work of the circulating waters. This of course does not satisfactorily explain the circumstance above alluded to —namely the difference in fissure fillings in a given mining district, for example, the deposition first of a copper vein and later of a zinc vein as at the Tiro General mine in Mexico, or the deposition first of a silver vein and later of a gold vein, as at the Mercur mine, in Utah. Nor does it explain the fact that many regions of igneous rocks are barren as to veins, in others the veins are scanty and poor, while a few show many veins with a high degree of metalliferous concentration.

The study of the phenomena of numerous mining districts in detail has finally led many of us to the belief that most ore-deposition (meaning thereby the concentration of the less common metals in workable deposits) is associated with igneous rocks because it is itself a *phase* of igneous eruption, that ore-deposition is accomplished mainly by magmatic solutions, and is

an intense phenomenon of brief duration;[1] that far from being due to universal processes it is a phenomenon no more common than the well-recognized phases of volcanic activity—in short that ore-deposition is not uniformitarian, but catastrophic in its nature.

Taking it for granted that these views are sufficiently well established, or at least sufficiently well understood, to pass over without further explanation, I wish to consider some possible relations of ore-deposition to other geological phenomena which are displayed in and have been studied in mining districts.

Let us take the phenomenon of faulting. It is well-known that many important mining districts are highly faulted, a fact which is a great vexation to the miner and a providential boon to the geologist. So frequently are ore-deposits associated with complex faulting that a vague idea of some kind of a connection often exists in the mind of the miner. I have repeatedly heard miners, complaining of the "broken up condition" of their ore-bodies, add philosophically: "Well, I suppose if we didn't have the faults we wouldn't have the ore." This superstition it has of course been our duty as geologists to enlighten, explaining that post-mineral faults are distinct phenomena, having nothing to do with ore-deposition.

It is nevertheless true that areas of intense mineralization are often areas of intense faulting, and I should like to investigate the question whether or not there can be any connection between

[1] A query put after the lecture shows the need of explanation of this conception. Geologic time is relative, and considering the time of ore-deposition as compared with the whole geologic history—even the history since the beginning of igneous activity of which ore-deposition is one of the manifestations—the phrase "brief duration" is accurate. If we envisage ore-deposition by itself, however, with the various successive stages which are shown in many districts, it is clear that measured by our time system, the years or centuries or millenniums consumed would be many. Roughly, the time occupied by ore-deposition, in my conception, is something like that occupied by an intrusion of igneous rock, to which the same remarks apply. We may and do consider an igneous intrusion as occurring at a definite point in the geologic history of a region; but in many cases there is evidence that the act of intrusion, if we consider it by itself, occupied an immense period of time, as we measure it in our lines.

the two classes of phenomena. It is not possible to go over the whole field of evidence. All that I can do is to cite a number of individual cases, the amount of data to be presented being limited necessarily by the time during which I can expect you to listen to me patiently, and not by the broader requirements of the subject. In selecting the cases, I will take some of those with which I am personally especially familiar, where I have done close, arduous, surface and underground work, and which have led me to the reflections which I shall suggest when I am through with my statement of the examples.

Most of you know the formerly very important silver-lead mining district of Aspen, in Colorado.

In the principal mining district at Aspen the period of igneous intrusion was followed by folding and faulting, and by a local doming-up of the strata, which, as I have elsewhere reasoned in detail, was probably due to the local pushing up of a column of molten rock which never reached the surface. "On account of its peculiar deformation this region (which is a few miles in diameter and is lifted in the center about a mile above the surrounding region) becomes isolated and conspicuous, even amid the tremendous folding and faulting which the adjacent areas show; and its difference from these adjoining areas becomes even more significant when it is considered that the center of greatest uplift and disturbance has also been the chief center of ore-deposition." The entire epoch of ore-deposition was short compared with the faulting, some of which took place previous to the ore-deposition, and along channels thus opened the ore has formed. Much of the faulting was subsequent, and the ore is displaced and broken up by these barren faults.[2]

I would have you note here five phenomena: intrusion, domal uplift, pre-mineral fissuring and faulting, ore-deposition, and post-mineral faulting, and their relation.

In the Georgetown silver-lead-zinc district in Colorado[3] the

[2] "Ore Deposition at Aspen, Colo.," ECON. GEOL., Vol. 4, No. 4.
[3] Prof. Paper 63, p. 161.

veins have formed along fault-fissures of usually slight displacement.[4] Subsequent to the various stages of vein deposition, the fault movements continued, and have resulted in uncemented fissures.[5]

At Leadville in Colorado the ores were deposited subsequent to an intrusion of porphyry. In the course of a private investigation there a few years ago I discovered a slight reversed fault on Carbonate Hill, which I called the Maid fault. The grouping of the ore-bodies in both the Blue and the White Limestone along the fault indicated strongly to me that the fault fissure had formed just subsequent to the igneous intrusion and had been the channel for ascending mineralizing solutions. Subsequent to the ore-deposition there was profound[6] and long-continued faulting to which the uplift of this portion of the Mosquito Range is at least partly due. On the eastern side of the Mosquito Range from Leadville, the London fault was the site of ore-deposition, in its earlier stages of growth.

This situation which I have interpreted in the Leadville district coincides with Emmons' findings in the Tenmile district, not far from Leadville, where he described two periods of faulting, one previous to the ore-deposition and one subsequent to it.[7]

The features I call your attention to in this section are the igneous intrusion, the closely following slight faulting, the intense ore-deposition, and the subsequent prolonged profound faulting accompanying or assisting in the uplift of the range.

I turn now to the San Juan country in Colorado, with which I am personally familiar, although the features which I shall point out are summarized from the work of the U. S. geologists

[4] After the lecture, a question was put as to what was meant by the term "slight displacement." The reply was that the term as used here means a relative displacement of a few inches up to a few feet only. In some vein-fissures the displacement is so slight as to be hardly measurable, if it indeed exists.

[5] These post-mineral faults vary from a few feet to (exceptionally) a few hundred feet.

[6] Many of these faults have several hundred feet displacement, running up to even a thousand feet or more.

[7] Georgetown Quadrangle, Prof. Paper 63, p. 109.

there, who have worked the various districts in detail. As noted by Cross and Howe, the San Juan Mountains represent a broad dome-like uplift, a structure which was part of the results of the widespread post-Laramie disturbances in the Rocky Mountain region. To this large dome structure smaller dome-like uplifts were added later, forming the Rico and La Plata Mountains, as noted by Cross and Spencer.[9] These smaller uplifts are regarded by the geologists mentioned as having a probable genetic relation to the older San Juan structure. Some observed deformation was undoubtedly due to intrusions of igneous rock, but it appears certain that on the whole the Rico dome and probably the La Plata dome were each formed by a single uplifting force, acting independent of any actual observed intrusion of liquid rock material. The San Juan structure is believed by them to have been an earlier and larger manifestation of the same force, pressing upward from below and not represented by any known intrusives.

A complex fault system was subsequent to the eruption of all the volcanic rocks, and therefore roughly contemporaneous with the upthrusting or doming movements.

The various sets of vein-fissures in these districts were mainly formed at the same general period, and filled during a single broad period of mineral infiltration, although I do not wish to lose sight of the fact that in regard to the detail of ore-deposition, there were distinct sequences of vein-deposition, which filled successively opened or reopened fissures.[10] As a rule the lodes occupy fissures of slight displacement. In the Silverton district it was Ransome's conclusion that the stresses which formed the vein-fissures were generated "by slight vertical movements following the enormous transfer of volcanic material from an intratelluric to a superficial position." The formation of fissures, with or without faulting, did not cease at the period of main vein-deposition, but has continued up to the present day.

[8] Geol. Atlas U. S. Folio 120, U. S. G. S., 1903, p. 84.
[9] Rico Folio U. S. G. S., No. 130, 1905, p. 11.
[10] Bull. No. 182, U. S. G. S., p. 66.

In the San Juan country your attention is called to the following phenomena: igneous intrusions and eruptions, fissuring and faulting, intense ore-deposition at a definite period, later than some faults and earlier than others, and the subsequent upward growth of dome structures, together with the development of complex faulting, which has continued to recent times or to the present day.

Turning now from Colorado, I wish to speak of certain districts in Mexico which are as familiar to me as any in the United States. At the Dolores mine, at Matehuala,[11] in the state of San Luis Potosi, the ores occur in the Sierra del Fraile, an isolated mountain which has the structure of a halved dome, with a dip slope on three sides, and an enormous normal fault on the fourth or east side. Areas of intrusive monzonite occur in the center of the half dome and the ores are located in the vicinity of the monzonite. These ores were formed subsequent to the intrusion, and are mainly associated with lime silicates, so represent a deeper-seated type, distinct from the predominantly silver, lead and gold-bearing ores of Colorado, to which I have just referred.

Investigation of the structure of the half-dome of the Sierra del Fraile shows that some force has arched up the Mesozoic limestone strata of the mountain, which broke away from the shale strata to the east along a jagged north-south line, so that the elevation was confined to the block on the west. The location of the monzonite porphyry intrusion seems to indicate a genetic connection between the intrusion and the dome-structure. Nevertheless, the proof is complete that the fault,[12] and consequently the dome, "originated not only after the intrusion of the porphyry, but after the series of phenomena of metamorphism and ore-deposition which ensued; that it originated at the very close of the vein formation and has had its remarkable growth since then."

These two lines of evidence are satisfied by the explanation

[11] ECON. GEOL., Vol. VII., No. 5, Aug., 1912, p. 444.

[12] This fault has a minimum vertical element of displacement of nearly a mile.

that the consolidated intrusive plug of monzonite was subjected to subsequent pressure at the base, due to the upward impulse of deeply buried unconsolidated portions of the magma column. As in the Colorado cases, the growth of the dome and fault seem to have been gradual, and probably still slowly progressing.

The copper ores of the mountain, as well as less conspicuous ores of lead, zinc, arsenic, gold and silver, were deposited along and from fissures in and near the monzonite, especially near its contact, and previous to the initial movement of the Great Fault just mentioned. There was a long and regular sequence of mineral deposition which followed the monzonite intrusion, beginning with various lime silicate depositions not accompanied by ores, leading up to ore-deposition in successive stages, and terminating in barren calcite veins; and the period of ore-deposition, with all its stages, was very short compared with the time indicated as occupied by the entire sequence.

One of the most interesting sidelights on the history of the region as revealed by the study of this long succession of mineral formation is the fact that the size (width) of the rock openings or fissures gradually increased from first to last[13]—from a condition where the shattered rock showed no continuous systematic fissuring to one where large and persistent fissures were developed. A gradual lessening of pressure suggests itself as the explanation, and it seems very possible that this pressure was that of overlying rocks, which were gradually removed by erosion during the process of mineral deposition. That the Great Fault which marked the growth of the domal mountain structure originated immediately subsequent to the ore-deposition is shown by the first fissure-filling of calcite along it, the calcite representing a definite last stage in the sequence of vein-phenomena. Later movement along this fault brecciated the early calcite filling, and the greater part of the fault movement was subsequent to all cementation, so that the main fault-fissures are unfilled, although the growth of the fault and the development of the dome must have occupied an immense period of time.

[13] I have in mind here the relative openness of fissures..

The hypothesis was arrived at, at Dolores, that "the mountain block began to rise when the downward pressure of the weight of overlying rocks, as it was lessened by erosion, reached the point where it was weaker than the upward pressure of the igneous column below."

We have to note, in this Dolores district, as successive stages, the intrusion of the monzonite, the formation of fissures of slight displacement, the filling of these openings by vein materials within a definite period, and the subsequent heavy faulting and the development of a domal structure coinciding with the area of intrusion and mineralization, which doming and faulting has steadily progressed to the present day, apparently keeping pace more or less with erosion.

In the state of Durango, in Mexico, the Velardeña district[14] has been an important producer of lead, silver, gold and copper ores. The San Lorenzo Range, which contains many of the most important ore-deposits, is of limited size, the main portion being only a few miles in length and less in width. Mesozoic limestones have been intruded by enormous masses of dioritic rocks, and the intrusions were followed by the formation of lime-silicates, both in the intruded and the intruding rock, and by ore-deposition, the ores being varied and comprising copper, gold, arsenic, etc. The evidence is that the solutions which formed the lime-silicates rose up along the consolidated pipes of igneous rocks, through cracks or fissures, and that in some cases these channels existed mainly along or near the contact. The mineral veins[15] are subsequent to the main formation of lime-silicates and have formed along fracture zones which were accompanied by only slight differential movement, or faulting.

"The strain which formed the first vein channels was afterwards continually felt, continually reopening the break as it was repeatedly healed by vein formation; and the openings became successively wider and wider, till at the end fissures of considerable width were formed and filled. The period of movement followed the igneous intrusion, and probably was dependent upon adjustments of equilibrium resulting from the intrusion."

[14] ECON. GEOL., Vol. III., No. 8, 1908, p. 688.
[15] *Op. cit.*, p. 713.

The latest stage of vein-deposition was barren calcite, as at Dolores, and this occurred, as at Dolores, at a period when heavy faults had already developed. The whole period of metalliferous vein formation occupied only the early part of the period of movement.

The San Lorenzo range in which these phenomena are shown, was found to be "an anticlinal range of deformation, this anticline having been impressed upon a plain of erosion underlain by highly folded and base-levelled limestone and covered with the products of alaskitic vulcanism." These surface alaskitic volcanics are of about the same age as the dioritic intrusions.

In the Velardeña district, then, you should note the following sequence of phenomena: the intrusion of a dioritic magma, and the extrusion of an alaskitic magma about simultaneously; the formation of cracks or fissures of slight displacement and openness, along which solutions rose which accomplished the formation of lime-silicate deposits and directly afterward of metalliferous veins, whose formation marked a clearly defined period; and the subsequent growth of large uncemented faults, developing strong fissures, at the same time as the uplift of the range to form what is apparently an elongated dome of limited proportions, whose size seems to have a relation to that of the known field of intrusion which occupies the center. In detail the displacement of these larger fault movements is such as to show that they have assisted in the formation of the dome, although much of the deformation seems to have been accomplished by flexing. In this case, as at Dolores, the progressive increase in the size of openings as time went on points to a decrease of presure; and as at Dolores, a progressive uplift to keep pace with the degradation of the range by erosion seems to be indicated.

Allow me now to note some features worked out by myself and assistants in another copper mine, this time one of those known as a mine of "disseminated ores" or commercially as one of the "porphyry coppers." At Ray, Arizona, perhaps at about the same geologic period as the phenomena at Dolores and Velardeña, that is to say, near the close of the Cretaceous, a great mass

or stock of granite porphyry welled up from below, through the earlier pre-Cambrian schists of the region. The Ray copper district lies near the borders of this stock, in the overlying schist, which is cut by dikes and protuberances from the main mass. There is no evidence of much faulting before the period of intrusion, but about the time of the intrusion fissuring was begun. The earliest fissures were of very slight displacement, and in the neighborhood of these the primary copper minerals were deposited, or in crushed zones of schist aligned similarly to these fissures. Subsequent to the mineralization, growth took place along certain faults, especially along the great Ray fault, and the present main mineralized area was uplifted, relatively to the country on the other or east side, perhaps one or two thousand feet. Erosion attacked the uplifted block and reduced it to the level of the other block, and Tertiary deposits were laid down upon the levelled country. Again, at about the end of the Tertiary, the same block, west of the Ray fault was again powerfully uplifted, probably upwards of a thousand feet, and the uplifted area was again attacked by erosion. The Tertiary rocks were stripped off from the schists and a Pleistocene desert wash deposit, called the Gila conglomerate, was formed. Later there was a general uplift of the whole region, and at the same time a reversed movement of a few hundred feet along the Ray fault, the block containing the main mineralized area this time subsiding, in contrast to its earlier repeated uplifts.

From pre-Cambrian to late Cretaceous times, or throughout the main portion of geologic history, there was apparently neither igneous intrusion nor ore-deposition in the Ray district, or till the great granite porphyry intrusion took place. This intrusion was preceded by a lesser diabase intrusion and followed by aplitic and pegmatitic dikes, pegmatitic quartz veins and the deposition of primary copper bearing pyrite. Of all the great number of faults, only a very few (and these may sometimes be relatively unimportant ones) are mineralized: most of them are barren. The period of ore-deposition was therefore, geologically speaking, brief and definite; and most of the faulting has been sub-

sequent. During all this later period of faulting and erosion there was apparently no renewal of primary ore-deposition or even of cementation of the fault-fissures. There was, however, a renewal on a smaller scale of magma migration, or volcanic activity. Between the first great uplift of the main mineralized region along the Ray fault and the second there was an important surface eruption of dacite; and, after an erosion interval, a shower of volcanic ash or tuff.

In the Ray district then, I would like you to note the following salient facts.

First, the apparent lack of either igneous intrusion or ore-deposition, or, so far as has been noted, of important faulting, from pre-Cambrian to probable Cretaceous times. Second, at the last-named period, the granite porphyry intrusion, accompanied or followed by fissures and fractures of slight displacement and by the primary ore-deposition. Third, that in the long period between Mesozoic times and the present, no ore-deposition has been noted in the district, although continued magma migration is shown by Tertiary volcanic activity. Fourth, that the main mineralized area, underlain by a portion of the granite batholith, had an upward movement or growth of at least three thousand feet, which growth occurred in two distinct and separate waves, and finally in very recent times, subsided a few hundred feet.

Please bear in mind that in speaking of the Ray mineralization I am speaking of the primary mineralization only. The present workable ore-bodies are the result of secondary concentration.

I will give you only one more example of these phenomena in a mining district.

At Tonopah, Nevada,[16] the earliest known rock is a trachytic flow, probably middle Tertiary in age. Directly after the trachyte eruption a system of east-west fractures, and north-east fractures were formed, with slight if any displacement, and the main mineral veins of the district were found along these. Subsequent to the vein-deposition strong faults, including powerful horizontal faults, developed gradually.

[16] ECON. GEOL., Vol. X., Dec., 1915, p. 713.

From the time of the first eruption till the late Tertiary, volcanic action recurred intermittently. Within the mining district itself an andesite was intruded, then trachy-alaskitic breccias, then later came an andesite surface flow of great proportions, and still later a series of alaskitic and rhyolitic surface flows and intrusions. The movement of the intruded magmas is shown to have been largely lateral, as well as vertical, to reach their present position. Subsequent to the trachy-alaskitic intrusions, there was renewed vein deposition, and subsequent to the main later rhyolite intrusion there was another period of barren vein formation, which cemented with barren quartz certain large flat fault-fissures that had been formed.

The active development of fault growth continued down to a relatively recent time and the more recent faults are entirely uncemented, though they have existed as channels of water circulation for a very long time. This stage of the faulting has been very active. By this post-cementation faulting the most intensely mineralized area of the district—Mizpah Hill—has been pushed up as a fault block above the rest of the country, the block being a truncated pyramid, bounded by four normal faults. On the other hand, faults have developed around some of the most recent volcanic necks which indicate local subsidence rather than uplift. They show that the volcanic necks sagged subsequent to consolidation and pulled down the adjacent intruded rocks with them.

I will not weary you tonight with any further examples. Did time and occasion permit, it would be of great interest to me to examine with you further examples of districts where I have worked out or helped to work out the geological relations; and to go further and cite districts described by others, where somewhat similar relations may be gleaned or inferred from the published reports.

Now what conclusions or working hypotheses may we formulate from the examples summarized? It is not my wish to try to state any rule, but I have gained the impression that there is a definite relation and sequence of igneous and dynamic history

connected with many centers of ore-deposition, and that numerous cases show more or less[17] the same sequence, suggesting the operation of widespread and orderly causes.

First, may we not say, to begin with, that in widely scattered localities, where for geological ages neither igneous intrusion, ore-deposition, nor deformation had occurred, repeated instances of all these three phenomena together or succeeding one another closely, indicates that magma migration, ore-deposition and dislocation or faulting are in these cases related phenomena?

Second, that the ore-deposition in these cases and in others of the same class, *followed* closely upon the intrusion, and therefore seems to have a direct genetic *dependency* upon the magma migration.

Third, that in all the cases described, the ore-deposition took place within a well-defined and geologically brief period.

Fourth, that in most of the cases cited above, the veins were formed in distinct fissures, often of great length and depth, but of very slight differential movement or faulting.

Fifth, that in all the cases mentioned, faulting of often great magnitude began directly after or during ore-deposition, and developed slowly afterward, through very long periods of time, in many cases down to a geologically recent period; and the later fault-fissures are uncemented by vein or gangue material.

Sixth, that in most of the cases mentioned the faulting accompanied a local domal uplift affecting a restricted area, which roughly coincided with, and seemed to have a location connected with, the area of earlier mineralization.

Let us start with the fourth point selected. What, let us inquire, is the cause of the repeated observation that mineral veins and ore-deposits are so often found to show a preference for fissures of very slight displacement? There is nothing in the physical nature of a large fault to discourage ore-deposition, as

[17] Please note the phrase "more or less." Each mining district has its own individuality; there are possibly no two exactly alike, though they may be grouped according to their resemblances. Neither do all mining districts, or even all those in a given region, show the complete sequences and relations described. In detail the history of each is different.

numerous cases will come to mind where distinct faults have been cemented by mineral veins. At Tiro General, S. L. P., Mexico, (near Charcas), for example, subsequent to an intrusion of granite porphyry into limestone, the porphyry intrusion sagged, producing a normal fault with a vertical element of displacement amounting to 160 feet. This fault-fissure was cemented by a wide blende-galena vein, averaging perhaps 10 feet in width. Later there was renewed faulting along this contact zone, the fault in part following the course of the earlier vein-cemented fault, in part taking a different course. The vertical element in this second faulting amounted to at least 250 feet. This new fault-fissure was cemented by a quartz chalcopyrite vein, having the same generous width as the earlier vein. The two veins have a combined width varying from 6 to 50 feet. At El Oro, Mexico, the great San Rafael vein follows a heavy pre-mineral fault, which has a vertical element of displacement of at least a thousand feet. The vein has a known extent, along the strike, of about 10,000 feet, and is over 100 feet wide in many portions, and for considerable stretches averages over 50 feet wide of quartz. There has been practically no movement along the fault since the vein-deposition.

The rule of the usual slight displacement of vein fissures, then, can only indicate that vein formation and ore-deposition have a direct relation to, and a definite position in, the dynamic history of the districts cited. The characteristic fissures of slight displacement, which in so many cases become the sites of ore-deposition, belong to the very beginning of the characteristic dislocation which has followed igneous intrusion in many important mining districts.

In many cases it has been noted that the growth of the faults increased with the removal of the rock overburden by erosion, and the approach of the faulted area to the surface. It might be argued from this that differential faulting is accomplished with difficulty under a heavy load of overlying rocks, and, as respects the slight differential displacement of vein-fissures, that these fissures were formed under the heaviest load of any in the whole

history of post intrusion faulting. In the case of the Aspen district, where I have estimated the height of the rock column overburden at the beginning of deposition as close to 15,000 feet, this argument presents at first sight some claim to consideration; but it fails as an explanation of the identical phenomena in ore-deposits of the shallow-seated Tertiary type, as at Tonopah, where the main veins were estimated to have formed at depths more properly measurable by hundreds of feet than thousands, and where the same peculiarities as to the vein-occupied fissures are observable. The phenomenon, then, is not a function of depth and pressure.

It may occur to you as surprising, as it did to me, that the evidence cited indicates that fault-fractures in these various districts began to develop, not at the time of the impulsion of large masses of liquid magma into the rocks in which they are found, but directly after the magma had settled into its new abode, so that the dislocations in many cases affect the consolidated lava as well as the intruded rock. The most disturbing period of igneous activity, it had always occurred to me, was the actual act of magma migration, and I would have expected to find that the fault system in the intruded rocks, even for a long distance away from the intrusion, would have not only been originated but developed to the highest degree during this period. Fractures and fissures in the intruded rocks must of course have been formed, but apparently many or most of these were penetrated by the liquid magma, and now form dikes, and not veins. In this connection I wish to inquire whether or not it is the case that igneous dikes as a rule occupy fissures of slight displacement. This is a point that I have never particularly investigated, and I should be glad to hear later your comments on the question. If it were true it would indicate that intrusion may be accomplished without minor complex faulting, although it is my impression that the act can hardly be accomplished without the formation and assistance of major faults—that is, relatively widely spaced faults of considerable magnitude.

This leads us to a consideration of the fifth point above. What,

may I ask again, is the explanation of the long-continued faulting concerning which we have just concluded that the vein-fissures in many cases mark the first stage?

This characteristic mainly post-mineral faulting took place after the actual observed intrusions, and mainly long subsequent to them. Evidently, therefore, the areas of complex faulting in the vicinity of or overlying intrusions in these districts are characteristic not of the period of intrusion, when it is a question of liquid magma, but later, when it is a question of solidifying or solidified magma.

The contraction of an intruded igneous body on solidification must generate local strains of varying intensity, depending upon the local amount of solidifying material. The contraction of a narrow dike, for example, will exert less force, tend to create less potentially open space, and require less adjustment in the intruded rocks than the contraction or solidification of a wide dike. The solidification of a dike will require less gravitative or vertical adjustment and more lateral or horizontal adjustment than the solidification of a sill of equal thickness, and in the case of intrusions of irregular volume and changing shape, the adjustments due to contraction will show great local variations, producing fault complexes. At Tonopah the distribution of heavy complex faulting in an area of volcanic necks and especially around the volcanic necks clearly shows that the faulting was here due to gravitative adjustments following consolidation, and the evidence that the amount of fault adjustment depends upon the volume of the consolidating lava (if indeed any demonstration of such a self-evident relation is necessary) is afforded by the more pronounced subsidence around the largest volcanic necks—Mt. Butler and Golden Mountain—as compared with that around the lesser volcanic necks; and the irregular fault blocks into which the subsided areas have been divided, show the varying quantitative strain set up by the consolidation of various portions of a single intrusion.[18]

[18] Experimental data as to the amount of contraction which takes place on the crystallization of an igneous magma are rare, and not conclusive on ac-

If then, adjustment strains consequent upon the consolidation of magma are responsible for much of the post-intrusion faulting in the districts cited, then the long continuance of the faulting (lasting in some cases through a large part of the Tertiary down to recent times) may indicate that consolidation has progressed through all this long geologic period. It may indicate that the strains due to contraction were ever repeated, as fresh portions of the magma crystallized, and that the overlying rocks were again and again adjusted along fault planes.[19]

Now in regard to the *second* point which I selected among those drawn from the consideration of examples: "that the ore-deposition *followed* closely upon the intrusion, and therefore seems to have a direct genetic *dependency* upon the magma migration."

The fixing of the age of the fissures which are afterwards filled by the mineral veins as coincident with and dependent upon the solidification of the magma, fixes the age of the ore-deposition as of the same general magmatic period, since the ore-deposition followed immediately upon the formation of the vein-fissures. This conclusion harmonizes with the theory of ore-deposits which, at the outset of my talk, I stated that I held and assumed you understood—namely, the theory that the vein-forming solutions are released and segregated through magma crystallization. Therefore the post-intrusion faulting is assumed to be due to contraction of the intrusive or migrated magma on consolidation, and the post-intrusion mineralization is assumed to be due to the crystallization on solidification of the magma; and if these as-

count of the difficulty or perhaps impossibility of duplicating in the laboratory the composition and environment of liquid rock magmas. Day, Sosman, and Hostetter (*Am. Jour. Sci.*, XXXVII., 1, Jan., 1914) have shown that under surface conditions the volume of a specimen of crystalline diabase was 11–12 per cent. less than for the same diabase reduced to a liquid condition, but they point out that the probable presence of volatile components in the original diabase magma introduces an uncertain element, which would probably modify the proportionate volumes obtained from the experiment.

[19] The different direction of successive movements along fault-planes, which movements vary from vertical to horizontal, may perhaps have some light thrown on them by this explanation.

sumptions are correct both the faulting and the ore-deposition, in the areas in question, are dependent upon the same operation, and so are genetically connected.

This opens the way for us to consider the *third* point that I brought to your attention a little while ago—"that in all the cases described, the ore-deposition took place within a well-defined and geologically brief period." In this respect, you will see, post-intrusion mineralization differs in a marked degree from its brother phenomenon, post-intrusion faulting, for though both depend upon the same operation, the one is relatively short-lived and the other very long-lived. If, then, magma consolidation lasts as long as post-intrusion faulting, why does not ore-deposition continually result from the mineralizing solutions residual from crystallization? To formulate a reasonable answer to this question I am afraid I shall have to refer to phenomena not yet mentioned in this paper. In a number of articles which I have written bearing upon the theory of ore-deposition I have tried to point out that ore-deposition probably took place within a certain definite range of temperature, and that from a given magma the same solutions appear to precipitate different metals in definite sub-ranges of this broader temperature range. Moreover, that as ore-deposition appears to result from magma crystallization or magmatic segregation, the conjunction of the required temperature range and the requisite stage of magma crystallization was necessary. Therefore the ore-deposits seem to characterize definite vertical zones, governed partly by temperature; while the post-intrusion adjustment of the overlying rocks as a consequence of sub-jacent contraction on solidification has no such zonal or temperature limitation, but operates from the locus of the solidifying mass clear up to the surface of the earth. With the progressive solidification downward of a given upthrust magma body, such as a volcanic plug or a stock, the temperature of a given overlying zone will decrease, and this decrease of the necessary heat limits will bring about the disappearance of ore-deposition from that zone; but not the disappearance of the faulting adjustments, which

may mark the progress of consolidation downward to a great depth.

And I may here remark that the relation of ore-deposition to vertical zones is very far from being a merely theoretical one. Everyone who is intimate with ore-deposits has many times seen the bottom of veins, and frequently seen the unfilled fissure proceeding downward with as much strength as it possessed above, where it had been cemented with ore. We have also seen, less frequently but in a sufficient number of cases, the top of veins, and seen the unfilled fissure proceeding upward past the vein-filling.

I have now taken up in some detail, although not in the original order, four out of the six points deduced from the consideration of the various examples of mining districts which were cited. Of the two remaining points, the first, that magma migration, ore-deposition, and fault dislocation are in some cases related phenomena, has I think been abundantly covered.

As to the *sixth* point, that in many of the districts ore-deposition was followed by and post-mineral faulting was accompanied by, "a local domal uplift affecting a restricted area, which roughly coincided with and seemed to have a location connected with the area of earlier mineralization."

These domal uplifts were subsequent to both intrusion and mineralization, and in the most pronounced of the cases cited their nature is almost unmistakable. The structure is precisely as if I punch with the blunt end of a pencil strongly upward into a sheet of paper and must have been made by the similar pressure of a similar instrument, and this instrument apparently was an intruded plug of consolidated igneous rock, forced upward by a localized pressure at its base, which we may assume to be the upward tension of the unconsolidated portion of the plug. The conclusion arrived at in one district, which applies equally well to some of the others, "that the mountain block began to rise when the downward pressure of the weight of overlying rocks, as it was lessened by erosion, reached the point where it was weaker than the upward pressure of the igneous column below," I regard

as a very important point; as, if true, it indicates a delicate static equilibrium or isostasy in the earth's crust, the comprehension of which is of far-reaching significance.

The uplift will of course avail itself of fault-planes if they exist or may actually create faults of uplift.[20]

I think we have inquired sufficiently into the relation of ore-deposition and faulting (especially complex faulting) to come to the conclusion, or if you prefer, to the hypothesis, that the ore-deposition and the subsequent faulting which we often find in our mining districts may not be disconnected phenomena and independent problems; that both may be connected with and localized by the single cause of local magma consolidation; and that each may be connected with a sometimes almost equally localized upward magma migration which forms a plug or stock, which even if not exposed by erosion may betray itself on the surface at the time of our examination by the evidences of local uplift, subsidence, or complex adjustment by faulting.

At the least we are justified in keeping these conclusions or hypotheses in mind, to be tested by that slow and patient process of honest comparison, rejection, and amendation which alone can give us the nearest approximation to the truth to which all good geologists are devotees.

[20] In the discussion which followed the question was asked as to the relation of this doming movement and faults of uplift to the complex faulting which, it has been assumed above, is in many cases due to differential subsidence on contraction and cooling of the underlying intrusive igneous rock. The conception is that while the consolidation of the upper portion of the plug produces contraction and subsidence and faults of subsidence, the upward tension of the lower liquid portion of the plug forces the upper portion upward as a whole, carrying upward both the solidifying plug, the overlying rocks and the already formed or forming fault-complex. Both forces apparently act simultaneously in many districts, and part of the complexity of faulting may result from the stresses and counter-stresses set up by the opposing tendencies, producing the varied successive movements along a single fault-plane such as are often recorded by successive sets of striæ. This in the cases where both are strikingly manifested. Naturally, a given mining district may possess a fault complex due to differential subsidence without the accompanying general uplift, or the uplift without any marked degree of complex faulting, or neither. As pointed out before, the history of each district differs in detail from others.

THE NEW ZINC MINING DISTRICT NEAR EDWARDS, N. Y.

DAVID H. NEWLAND.

INTRODUCTION.

GENERAL REMARKS ON ZINC IN PRECAMBRIAN ROCKS.

Precambrian zinc ores, if not exactly rare, are relatively uncommon in a commercial way. It would appear from a general survey of the sources of present ore supply that mines in the earliest formations occupy a very subordinate place, both as to number and relative contribution. The deposits at Franklin Furnace and Ogdensburg, N. J.—now definitely assigned to the Precambrian, though once considered as possibly Paleozoic in stratigraphic relations—constitute about the only well-known examples of active producers of zinc ores from these surroundings, as also they are quite unique from a mineralogical standpoint. Elsewhere the ores are of the sulphide type, either blende or oxidized compounds derived from it, and are mined from formations ranging from Paleozoic to Tertiary age.

The disparity in the geological distribution of zinc, distinctly indicated by the derivation of the mine output, is a matter that invites inquiry, for it depends no doubt on factors that have a broad application and mayhap practical significance for the conduct of field exploration. It is a subject, however, that lies beyond the scope of this paper and is referred to only for the purpose of pointing out one or two features which have been suggested in the study of some newly opened deposits in the Adirondacks, where the ores are blende, carrying pyrite and subordinate galena, and occur in crystalline limestones of Grenville age. The deposits, it may be mentioned, are in many respects similar to the occurrence at Long Lake, Ontario, described by Uglow[1] in a preceding issue of ECONOMIC GEOLOGY.

There is little basis apparently for seeking a clue to the problem presented by the distribution of zinc ores in the processes directly concerned with metallization. No lack of efficient media for the concentration of metals in Precambrian time seems likely in view of the deposits of other kinds, *e. g.*, iron, copper, nickel and gold which exist in relative abundance. Concentration and deposition were effected at different intervals during that long stretch of time; altogether the results indicate a multiplicity of ore-forming agencies at work, comparable in a broad way, as well as in particular instances, to the processes that have gone on more recently.

Geological environment has to be considered as a possible factor, for it is a matter of common observation that certain rocks exercise a selective influence upon ore-bearing solutions, favoring the accumulation in their vicinity of certain kinds of ores, while others are devoid of bodies of similar type. This resolves itself into an inquiry as to the quantitative development of different rocks in the Precambrian terrane and their points of contrast with the stratigraphy of succeeding periods. There is need of caution of course in using present observations for basis of conclusions as to the environment so far back; for the effects of erosion in the interval have been to remove many thousands of feet from much of the old land surface and to accentuate in so doing the importance of the harder more resistant formations at the expense of those of weaker character. Yet, with all allowance for changes of the kind, it is quite possible to derive certain information of value to the inquiry in hand.

One of the outstanding features of Precambrian stratigraphy is the small part taken by carbonate rocks. Moreover, where these occur in greatest force they belong to the very base of the geological column. It appears that throughout the longer part of the interval, as represented in the sequence of rocks to be found over wide tracts of present-day Precambrian strata, there were no limestones in course of formation. This is true of the Adiron-

[1] "Ore Genesis and Contact Metamorphism at the Long Lake Zinc Mine, Ontario," ECON. GEOL., Vol. XI., No. 3, 1916.

dacks, of the eastern Laurentian highland embraced in the St. Lawrence region, and of the Great Lakes country. Less is known about the conditions elsewhere. In the Appalachian Piedmont belt occur small areas of crystalline limestones whose precise position in the series is not certain, although definitely assigned to the Precambrian, like the white crystalline limestones in the New York-New Jersey Highlands.

The Grenville limestones, it is certain, once spread over a much greater area than they do now, since they wasted under erosive and solvent agencies more rapidly than the silicate rocks with which they are associated. In the Adirondacks they are more in evidence on the borders than in the elevated region of the interior. Furthermore, the vicissitudes of igneous invasion to which they were repeatedly subjected in Precambrian time and by which they were engulfed, absorbed or metamorphosed, contributed materially to their diminished areal importance.

These old limestones, now broken up, folded and much altered locally, must have offered congenial ground for the collection of zinc ores, and it is probable the processes of concentration and precipitation of the metal during Precambrian time were largely centered within these rocks. For although they have been modified structurally and by metamorphic influences, they present no essential differences that would tend to remove them from the operation of the general methods of mineralization that have taken place in later limestones. In other words, they should contain zinc ores, if any were deposited, of similar character to those found in recent beds, allowing for the effects of differential erosion and metamorphism upon the deposits.

There is considerable evidence to show that the limestones were fairly well mineralized, and that they constitute a distinct exception to the general rule applicable to the Precambrian rocks as a whole. It is quite likely with exploration further confirmation of this statement will be forthcoming. As yet little attention has been paid to the discoveries of blende already reported from different localities in the Grenville limestones, of which some have been known for years. The general impression seems to have

been that the conditions of environment were unfavorable to the existence of blende in mineable bodies, for that only can explain the small amount of exploration carried out in comparison with the work done in other regions where ores are found in the unmetamorphosed limestones of later age. The mine at Edwards is one of the few instances where persistent development has been undertaken on a body of zinc blende in the Grenville.

While it is reasonable to conclude that zinc in the Precambrian limestones was concentrated and deposited in the same way as in the later limestone formations, the older deposits in places have been subjected to considerable changes from metamorphic agencies. This is not necessarily a general condition, for the period of deposition locally may have been so late in the Precambrian that they show little more effects of the kind than bodies of similar ores in the so-called unmetamorphosed strata. Secondary silicates, especially tremolite and diopside, are common associates of the Grenville ores, but their presence does not warrant the conclusion that the metallization was antecedent to the period of metamorphism. In the Edwards district there is evidence that the contrary was the case. The presence of these silicates has involved certain consequences through the process of hydration by which they have been largely converted into talc and serpentine; the increase of bulk through these changes leads to local brecciation and movement resembling the effects of regional pressure.

The work of erosion in its relation to the deposits may be of the greatest importance. It is, however, a very variable factor. Where the limestones have been exposed to atmospheric agencies since Precambrian times there is likely to be little left of them except the deep infolded or downfaulted portions. Such ores as these may contain would naturally have little resemblance to open-fissure fillings or deposits formed near the surface. In case the beds have been covered by later formations and thus protected from erosion during most of subsequent time, as is true of the Grenville rocks in the St. Lawrence River area of Ontario and New York which was submerged in the Cambrian period,

they may still retain much of their former force and afford propitious conditions for the preservation of ore deposits. It is apparent, however, that, other conditions being equal, the ores in the deeper zones of concentration are more likely to have been preserved than those in the superficial layer, such as for example are found among the Paleozoic limestones of the Mississippi valley.

MINING DEVELOPMENTS IN THE EDWARDS DISTRICT.

The first ore shipments from Edwards on a commercial scale were made in 1915, although development work had been in progress for sometime previously. The output so far has come from a single mine owned by the Northern Ore Co. and situated just outside of Edwards village, on the road to Trout Lake.

The existence of zinc ores in the vicinity has been known since the early part of the last century. Mention of some of the localities is made by Ebenezer Emmons in his preliminary report on the second district of New York, published in 1838. The surface showings, if they had been in an active mining district, would have received some attention at least, but nothing of real consequence was done anywhere until the present enterprise started to prospect the body which it now works. This deposit is opened by an incline to a depth of 525 feet, following the dip which ranges from 25°–60°. A series of levels, at intervals of 100 feet or less, extend along the course of the ore to a maximum distance of about 600 feet. From the levels cross-cuts give access to a second body in the hanging which also appears at the surface and has been drifted on for a maximum length of 250 feet. Another shaft has been sunk about 800 feet away on a third body, but this had not yet produced at the time of the writer's visit in the summer of 1915.

Several prospects have been uncovered in the stretch of the limestones southwest of Edwards, as far as Sylvia Lake twelve miles distant. As yet none of them have been tested thoroughly, although some show promise. The results of the Edwards venture, particularly with respect to the continuity of the deposits in depth, have been awaited with much in-

terest for the guidance they would afford for exploration elsewhere in the district. There is no doubt now of the commercial importance of the occurrence, as enough ore has been uncovered in the mine workings or indicated by drilling to place the property on a successful basis.

It is too early to express an opinion as to the contribution that may be expected from district as a whole; but in view of the high average tenor of the ores and the favorable indications of the persistence of the ore zones the outlook for the enlargement of the mining industry is distinctly encouraging.

SITUATION AND TOPOGRAPHY.

Edwards is a village and township on the northwestern border of the Adirondack highland. It has become well known in the mining world for its fibrous talc—an article of importance in the paper industry—obtained from several localities in this and the adjoining township of Fowler (see Fig. 31). The talc and

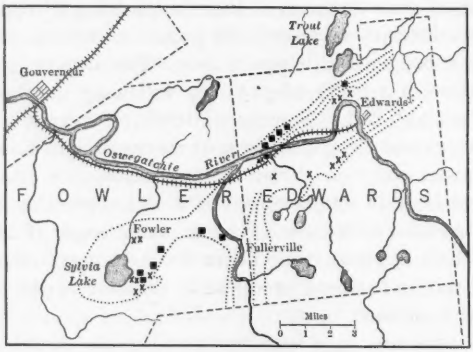

FIG. 31. Sketch map of Edwards district.

blende deposits both lie within the same belt of crystalline limestones and in places are closely associated, as on the southwest near Sylvia Lake.

In this part the Adirondacks possess little of their usually rugged aspect. They have the character rather of a plateau of moderate relief that slopes north and west and joins outwardly with the St. Lawrence lowland without any sudden topographic change. There is no break also in the continuity of the Precambrian crystallines beyond the Adirondack confines; the strata extend across the lowland, here and there concealed by a veneering of Potsdam sandstone, to the edge of the St. Lawrence river, thus bridging here the gap between the Adirondacks and the Laurentian area of Canada.

The low relief of the district is an inheritance from early Cambrian time. Without entering into particulars, it may be said that before the opening of the Paleozoic era the crystalline rocks had been exposed to long-continued denudation which removed many hundreds and probably thousands of feet from their surface, smoothing out the irregularities of topography and reducing the surface to a peneplain which then was submerged and received the deposit of Potsdam and Ordovician strata. The subsequent uplift terminated the marine sedimentation and during all of the Mesozoic and later time, except for the glacial episode, the region was an exposed land surface. The action of erosive agencies has sufficed to remove the Paleozoic cover and expose the crystallines once more, but the final disappearance of the former did not take place probably until Pleistocene time, so that the old Cambrian peneplain is still one of the dominant features in the topography.

GENERAL GEOLOGY.

The rock geology of the Edwards district partakes of the general character of that of the Adirondack region as a whole. The formations include the Grenville series of metamorphosed sediments; granite intrusives which consist mostly of a red biotite-hornblende rock in bosses and dikes; pegmatitic aplitic and quartz offshoots of the red granite; and trap dikes, which were the last of the Precambrian rocks in relative age. The former presence of Paleozoic strata has been referred to, and will not be given further consideration. During the Pleistocene the ice swept over the

region and no doubt assisted in the removal of the sedimentary mantle but did not deeply erode the crystallines. It left a thin cover of drift, and along the Oswegatchie river numerous terraces evidence a period of flooded waters succeeding the ice.

Grenville Series.—The Grenville, so called from analogy with the rocks of the Canadian Grenville area, include a great thickness of limestones, quartzites and schists which appear to be conformably interbedded and doubtless represent a single series of old Precambrian sediments. Among them the limestones, now thoroughly crystalline and much folded and contorted, demand special attention. In the Edwards belt the rocks are dolomites, or at least carry considerable percentages of magnesia, and contain varying amounts of siliceous impurities—quartz, tremolite, diopside, talc and serpentine. Occasionally exposures are found which are free of such admixture. Their main development is in a belt that extends from the vicinity of Sylvia Lake on the southwest to several miles beyond Edwards village on the northeast and is from one to three miles wide. The belt is not without inclusions of other rocks, but in the main consists of limestone. Its outlines are traced on Fig. 31. The structure of the limestones is not fully evident. The dip is everywhere northwest, at angles ranging from 25° to the vertical while the strike usually follows the axis of extension. The belt may represent a compressed fold, of which only the middle axial part is now preserved.

Quartzite, often pyritic, occurs interbedded with the limestones. It has the character of a hardened sandstone. White vitreous quartz free of pyrite forms thin bands within the limestone, and on eroded surfaces often gives a peculiar ribbed effect to the ledges, the bands alternating with layers of the limestones. In places they seem to be parallel with the bedding, yet elsewhere are observed to cut across it like veins following parallel joints or fissures.

The Grenville schists consist of dark quartzose varieties, with biotite and hornblende as iron-magnesia constituents, and small amounts of feldspar. Granitic injection is a common feature.

Granite.—Granite is the principal igneous rock in the district and occurs in many separate bosses and dikes on the borders of the limestone belt. Whether these all belong to a single period of intrusion is not evident as yet, but there is a marked degree of similarity in the petrographic characters of the different exposures. The principal type is a massive, coarse, frequently porphyritic type, showing compression effects only locally and has a fresh look, the color being pink or red. This variety is widespread and has exerted a profound influence upon the earlier rocks with which it contacts. The schists, especially, have undergone remarkable changes of structure and composition through the invasion and diffusion of this magma which seems to have been very tenuous. Within the limestones are developed pyroxene and amphibole minerals, scapolite, fluorite, titanite and other minerals that can be referred to its influence. Dikes of pegmatite and quartz veins accompanied its intrusion, as a final feature.

A porphyritic granite occurs widely along the southern border of the limestones between Fullerville and Edwards. The exact extent and form of the exposure have not been determined, but it is probably a large body and may be related to the great bathylith described by the writer[2] as occurring in the area immediately south of the Edwards district. Similar granite is exposed widely over the western Adirondack region.

Trap.—Dikes of basaltic rock represent the last of the Precambrian intrusions. They are small and in this part rather uncommon. This intrusion has had no particular influence upon the other rocks.

DISTRIBUTION OF ORES.

The ore localities so far discovered all lie within the main limestone belt, in the section from Edwards to Sylvia Lake. There are a dozen or more separate outcrops, mainly along the contact of the limestone and the bordering granite and schists. They

[2] "Quarry Materials of New York," N. Y. State Museum Bulletin 181, 1916.

do not favor one side exclusively; at Edwards they occur on the north side, within a short distance of the schists, under which they are carried by the dip; south of Edwards most of the prospects lie to the southern border, in places within 100 feet of the latter, and their northwesterly dip carries them away from the schist contact.

It will be seen from the map that the talc mines, also, are grouped mainly along the contact, although they may not be in proximity to the zinc ores. In the vicinity of Sylvia Lake the two are closely associated.

FORM OF THE DEPOSITS.

In shape the ore bodies show individual variation, but the predominant form is lenticular. On the surface they appear as bands or stripes of ore within the limestone that gradually thin out as they are traced along the strike for a few hundred feet at most. In a few places they have a rounded outline, somewhat drawn out on the strike and contracted at right angles to it, a form that may be called a shoot. More rarely they possess no regularity that admits of geometrical definition.

The best sections underground are obtained in the Edwards mine of the Northern Ore Company. The body explored by the main shaft outcrops on the eastern side of a low limestone ridge as a solid band of mixed blende and pyrite, the walls at the opening being well-defined and parallel. The ore is 4 feet thick at the outcrop but gradually increases in depth to a maximum of 14 feet on the 200-foot level below which it again thins down, but still persists at 500 feet. The longest level is 600 feet, but the southern end of the workings are terminated by the deep valley which extends well below the present alluvial flat over which the Oswegatchie flows. The form of the body thus appears to be an attenuated lens, but modified by compression so as to develop minor rolls and pinches, and also warped out of plane in a broad arc which curves around from the shaft to the south through an angle of 90°.

The ore is sharply defined against the walls as a rule, a knife blade sufficing often to separate the ore from the limestone. One wall at least is always clean, while the other may be frozen to the ore, although not invariably so. On the free side there is often a thin gouge of decomposition products, showing that there is passage for water. The ore itself carries little seams of talc and serpentine, the fillings of small fractures developed after the deposition of the sulphides. Where the ore is tightly frozen to the limestone, wisps and stringers of the sulphides make off into the latter for a distance of a foot or two, and afford some resemblance to a gradation contact in such places.

At the north shaft at Edwards, the deposit contrasts very markedly with the features just described. It consists of a zone of the limestone heavily charged with serpentine, carrying blende and pyrite in bunches and disseminated grains, with a gangue in which serpentine is most prominent. The zone is irregular, but some 15 feet across in the widest parts. Underground the ore, according to Mr. Grugan, manager of the Northern Ore Company, seems to develop the form of a shoot. At the surface it shows brecciation, being divided into angular fragments that have been recemented by vein serpentine and calcite. There has been some movement in the mass as shown by slickensided surfaces. The expansion of the volume through the hydration of the original silicates (mainly diopside) may account for some of the pressure phenomena.

The shoot form is exemplified by a deposit on the property of the Dominion Company near Sylvia Lake to which the writer's attention was called by J. H. McLear, secretary of the company. The deposit was opened years ago for iron ore, which exists in the form of hematite as a capping to the sulphides that are encountered at less than 100 feet from the surface. The pyrite-blende mixture is very fine in grain and has a gangue of quartz which is quite exceptional for the ores of this district. In the samples examined microscopically there is evidence of the late infiltration of the quartz which has made room for itself at the expense of the sulphides, and of the hydrated silicates. The iron

released by surface oxidation has been carried down and reprecipitated in the form of hematite around the sulphides.

Disseminations of blende and pyrite occur in the limestones, forming a low-grade ore. Such deposits have no well-defined boundary, as seen at the surface, though they tend toward the band or lenticular form. There has been no deep exploration of such bodies.

In general the characteristic form of the ore-bodies may be called lenticular. Individually the lenses vary in size and proportions; yet little is known at present as to these particulars. The Edwards deposits now worked consist of lenses with a length and breadth from 20 to 50 times their maximum thickness.

COMPOSITION.

Most of the blende is the dark variety, the black jack of miners, opaque in the hand specimen. Very subordinate in occurrence, but still found in occasional outcrops, is a lighter brownish yellow variety, free of iron. Pyrite is always met with in the darker ores and necessitates milling treatment to reduce the iron, even if the grade be high enough in zinc to meet the metallurgical requirements. It ranges from a few per cent. to a third or one-half of the total mass, but in the average perhaps is less than 25 per cent. It is scattered through the ores in roundish particles of uniform size, usually of similar proportions to those of the blende.

Galena occurs in the Edwards ore to a small extent—a fraction of 1 per cent. in the mill run—and is seldom visible in the hand specimen. At the north shaft a few pieces of ore were picked up which showed galena in cleavage pieces an inch or so across. It is most abundant on the Balmat vein near Sylvia Lake where the ore in part is mixed blende, pyrite and galena, with quite as much of lead as zinc. This deposit was the first ore to attract notice, and was worked in a small way seventy-five years ago, for the purpose, it is said, of extracting the silver which the galena carries. It was too complex a material, apparently, for successful treatment in that day.

Barite occurs usually to the extent of a few per cent. in the Edwards ore. The other non-metallic constituents are carbonates and secondary silicates, the latter altered more or less to serpentine and talc.

A sample of the ore, taken from a large chunk recently presented to the New York State Museum by the Northern Ore Company, was analyzed by R. W. Jones of the museum staff with the following results. The sample, it may be explained, is above the average in metallic tenor, but it was selected rather with a view to the composition of the blende than to that of the ore in a large way.

SiO_2	5.69
Al_2O_3	.36
CaO	1.45
MgO	.61
BaO	1.46
CO_2	n.d.
H_2O	n.d.
Zn	51.43
Fe	5.80
Cd	n.d.
Mn	n.d.
S	30.86

The carbon dioxide, water, cadmium and manganese were in amounts of less than 1 per cent. each. The silica is above the amount needed to satisfy the bases, indicating a little free quartz. The iron in the zinc is not specially high, since 3.76 per cent. of iron is required for combination with sulphur as pyrite, of which the calculated percentage is 8.06.

PHYSICAL APPEARANCE.

A constant feature of the ore, however it may vary in other particulars, is its compact, even-grained texture. There are no free spaces or vugs, except as they have been formed by solution or movement after the sulphides were deposited. The mineral particles are in close contact on all sides, so that the only openings are small pores which exist in every rock. The existence of thin partings of talc and serpentine have already been noted in

the description of some of the deposits, but it is evident in most instances that such cracks are due to movements arising from strain and filled subsequently by infiltration rather than original openings. The relief of pressure through removal of the overlying strata and the expansion of the mass as a result of serpentinization of the silicates suffice to account for much of the local fracturing that is observable.

The blende and pyrite are developed as rounded and subangular grains, approximately uniform in size within the limits of a hand specimen. They rarely show an approach to crystal form. No crystal boundaries in fact have been observed in the blende, although occasionally a grain of pyrite may be seen to have one or more plane surfaces that suggest crystal faces.

The grain is coarser in the high-grade ores, such as are exemplified by the well-defined lenses, than it is in the disseminated or leaner ores in which the sulphides are scattered through a groundmass of carbonates and silicates. In the latter the grain diameters are of the same order of magnitude as those of the nonmetallic minerals, whereas in the richer ores they are likely to be much larger. The variation between different deposits in this respect is very marked. Samples of the rich blende from Edwards show individual cleavage surfaces an inch or more across; the pyrite, of which little is present, is inclined to be more finely divided, usually not exceeding one fourth of an inch in diameter. Among the deposits of disseminated sulphides the ore particles range from one eighth of an inch for the largest down to mere specks visible only with a lens.

A general absence of banding, crustification and similar structures characteristic of ores deposited in open fissures near the surface, or of vein fillings, is to be noted for all the deposits that have so far been uncovered. This feature is believed to be a primary one, essential to the conditions under which the metals were deposited. There is no indication that such structures were once present and were afterward obliterated by anamorphism, as might be conceived to be a possible condition. The evidences, so far as they go, tend to confirm the view that the ores have not

undergone any great change in physical arrangement or textural features since they were laid down in their present places. This does not mean that there has been a total absence of compression and anamorphic influences; on the contrary such influences were active for the long period during which the deposits were still deeply buried under the load of overlying crystallines and the later one when they were covered by a heavy but unknown thickness of Paleozoics; but they were never of such magnitude as to effect a thorough breaking down and recrystallization of the metallic minerals, as would have resulted undoubtedly if they had participated in the general metamorphism that has affected the limestones, schists and gneisses of the district.

In addition to the scattered particles of silicates—which are always present even in the richest ore—there are nodules or bunches of these minerals of larger size, sometimes measuring several inches or as much as a foot in diameter. They have a subrounded to spherical shape and are made up chiefly of diopside and the secondary silicates—talc and serpentine. Entirely similar nodules occur in the country limestones. Their centers are quite free of sulphides, but along the edges the latter penetrate into them and occasionally are seen to extend for some distance from the borders without interruption. In the case of the very small nodules, which are almost entirely changed to serpentine, the form is more irregular and often quite angular. The larger ones have a talc core, in which residual grains of diopside may be observed under the microscope, surrounded by a rim of serpentine.

MICROSCOPIC RELATIONS AND EVIDENCES OF PARAGENESIS.

The study of the microscopic features of the ores and associated gangue minerals affords much of interest for the consideration of the origin and subsequent history of the deposits. As a basis for the present discussion a number of thin sections made from samples taken from different localities were examined. Unfortunately the sections do not lend themselves to photographic reproduction, since the blende is only slightly translucent and can

not be distinguished from the pyrite in transmitted light, while the intimate mixture of talc, serpentine, diopside and tremolite is equally difficult to separate in the photographs.

The accompanying micro-drawings present some of the significant characteristics of the sulphides in their relations to the country rock and the gangue; they are particularly illustrative of the rich ores which occur in well-defined lenses, as they have been made from samples collected in the workings of the Edwards mine.

It will be seen (Fig. 32) that the sulphides—blende and pyrite—form a network in which the silicates occur in the meshes, and

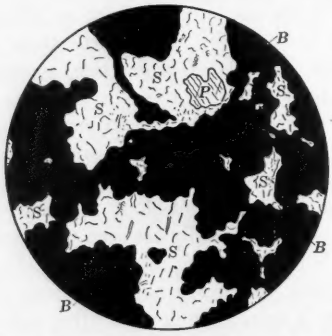

FIG. 32. Micro-drawing of ore from interior of deposit. B = blende; S = alteration products, mostly serpentine and talc; P = pyroxene.

that the latter minerals have deeply indented, irregular boundaries, in which there is no trace of crystal outline. The sulphide particles, in other words, fill the place that would be taken by the carbonates if they were present, but with the added condition that through their participation the silicates have lost the usual regularity of form that characterizes their appearance when surrounded by carbonates. It would seem evident that the original silicates, that is diopside and tremolite, belong to an earlier generation than the ores and in contact with the latter have been more or less replaced. There is seldom any appearance of crystal

form left in the included silicate particles, although such is common in the silicates distributed through the limestone. It will be seen also that the size of the silicate particles is extremely variable, contrary to their normal condition outside the ore zone.

FIG. 33. Micro-drawing of contact of ore and limestone. B = blende; Py = pyrite; c = limestone; T = talc pseudomorph after tremolite.

On the contact of the ore and the wall rocks the carbonates come into prominence and here there is less evidence of metamorphic action upon the silicates. A part of the contact is shown in Fig. 33. The line of contact as magnified seems quite irregular, although with the unaided eye it appears straight and sharply defined.

In vicinity of the contact the condition illustrated in Fig. 34 is quite frequently to be seen. Here a stout prism of the original silicate (diopside) now completely altered to serpentine, is nearly enclosed by sulphides, the carbonates appearing on a part of the borders in the same relation as would be assumed by the blende and pyrite if they had filled the entire space about the silicate particle. The fractured appearance of the sulphides in such circumstances is characteristic. The small openings along the fractures are filled with vein serpentine continuous with the central mass from which they radiate.

The blende and pyrite belong to the same period of genesis and

must have been precipitated without any marked interval in the process, if their times of deposition did not actually overlap. The tendency of the blende to surround the pyrite—which is noted in the disseminated as well as in the high-grade ores—and the

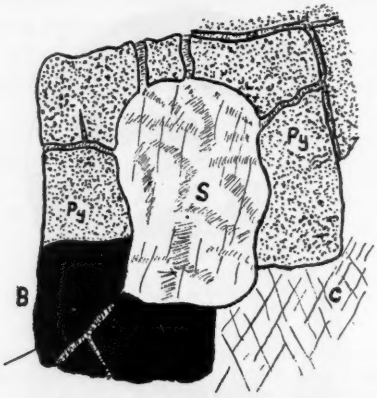

FIG. 34. Micro-drawing to illustrate relation of ore and gangue in vicinity of contact. S = serpentinized diopside; B = blende; P = pyrite; C = carbonates.

automorphic boundaries of the latter toward the blende, sometimes observed, seem to show that the pyrite began to form first.

The original silicates are in an advanced state of hydration. Very often there are no remnants to be seen of the tremolite and diopside. The change to serpentine or talc, as the case may be, is related apparently in some way to external factors, for the two secondary minerals do not occur haphazard as if formed under the same set of conditions, although either may be produced from the same parent mineral. At present serpentine is the principal result of hydration; talc is more rarely to be observed under conditions which show its contemporaneous formation. The conversion of talc into serpentine, as illustrated by the occurrence of nodules with a core of the former and a rim of varying thickness of the latter, gives weight to the deduction that

serpentine is better adjusted to the present environments. It appears probable that the talc is the product mainly of hydration in the lower zone of katamorphism before the beds were exposed by removal of the overlying strata, a condition which would involve heat, pressure, and limited oxygen supply; whereas surface temperatures and pressures and plentiful supply of oxygen promote the formation of serpentine.

EVIDENCES OF THE AGE OF THE DEPOSITS.

The geological associations afford no direct clue as to the age of the ores. The strata all belong to the Precambrian, except the drift and alluvial beds, and there is no clear case of intrusion by offshoots of the granite bathyliths or by trap which would establish their Precambrian age beyond doubt. The only evidence so far discovered is the occurrence of feldspar at the bottom of the Edwards shaft, on the hanging side, reported to the writer by Mr. Grugan; from this it is inferred that a body of pegmatite intersects the overlying limestone and may be in contact with the ore, but the latter point has not yet been settled.

The view that the deposits are Precambrian, therefore, rests upon indirect evidence. It finds support principally in the features surrounding the physical nature of the ores themselves which have already been set forth. The compact granular character of the ores, the absence of open spaces and of vein markings, and the relation of the sulphides to the associated minerals, all point to accumulation of the ores before the anamorphism of the limestones was completed, or formation at depth, before the enclosing limestones had reached their present exposed position. Inasmuch as there has been no extensive erosion of the limestones, commensurate with the required changes in vertical position, since the opening of Paleozoic time, the conclusion is inevitable that the period of deposition traces back to the Precambrian.

As examples of ore formation in the Grenville under surficial conditions and of more recent date, mention may be made of the veins of galena with subordinate blende that occur in the limestones of Rossie and Macomb townships, west of Gouverneur, of

which an account has been given by C. H. Smyth, Jr.[3] These ores occupy fissures that intersect the Precambrian formations and extend upward into the Potsdam, where this is still present. They bear little resemblance to the ores under discussion, the sulphides being in coarse, often crystallized particles in a calcite-fluorite gangue which is free of silicates.

ORE GENESIS.

The problem of the derivation of the ores is not simplified materially by what has been set forth in regard to their age. So far as the information goes they may have been deposited at any time in the Precambrian—either as the result of precipitation in open waters along with the limestones, or have been introduced by concentrating agencies at any later period before the general erosion that preceded the Paleozoic submergence.

It is not believed, however, that there is any substantial basis for the sedimentary view which considers the lenses of high-grade ores as original beds in the limestones. Apart from the fact that ores of that type are not definitely known to occur in unmetamorphosed strata, there is much evidence opposed to that explanation in the field relations already described. The shoot-like deposits at Edwards and near Sylvia Lake do not conform to any structure resulting from sedimentation even allowing for possible modification by regional compression and metamorphism. Again the ores are not confined to any one horizon, although they do favor the borders of the limestones; on the assumption of bedded relations it is quite impossible to bring the ore localities into alinement even by allowing for the existence of two or three separate horizons.

The criteria afforded by field observations are strengthened and supplemented by the study of the more intimate relations of the ores to the enclosing limestones and the textural features resulting from the associations of sulphides and the silicates which constitute the gangue. If original beds the sulphides were in

[3] "The Rossie Lead Veins," *School of Mines Quarterly*, Vol. XXIV, No. 4, 1903.

place before the lime-magnesia silicates had been developed as an effect of metamorphism. The evidences all seem to point to the opposite of this relation: for the silicates have undergone more or less replacement by the sulphides which moreover surround the former and hold the same place in reference to them as the carbonates do in the usual limestones. It would be expected that the ore-bearing solutions in process of depositing their loads should first attack the carbonates and remove them, after which they might react upon the silicates to a greater or less extent.

The alternate view that the ores may have existed in place before the anamorphism of the limestones, and were rehabilitated as it were by the effects of this, as explained by Uglow in the paper on the Long Lake deposit, does not meet the conditions. It is likely of course that the textural features would undergo more or less change through a recrystallization of ores and gangues as demanded by this view, but not to the extent of reversing the relations throughout.

The introduction of the ores seems to have occurred then after the Grenville strata had been subjected to regional compression and had received most of their present characters. This period of intense anamorphism was in early Precambrian time and before its completion came the intrusion of the red granite which shows more or less modification by regional compression.

The deposition was mostly as replacement, whereby the agencies effective in the concentration and precipitation of the sulphides made room for the later by solution of the carbonates. It has been noted that the ore is often frozen to the limestone without any indication of an open channel through which the solvents circulated. Yet in the Edwards mine a free wall may occur on one side, suggestive of an original joint or fracture on the course taken by the solutions.

The occurrence of the deposits along the borders of the belt is quite in consonance with the results to be expected from this method of accumulation. The tendency of the circulations to spread beyond the limestones would be inhibited by the dense more resistant schists: also the silicate bands that occur on the

edges of the belt have a more open texture than the carbonates free of such admixture.

It is a reasonable inference from the described conditions that the deposits were formed at considerable depth; the period of metallization ensued upon the silication and recrystallization of the limestones which took place when the latter were deeply buried.

The participation of igneous agencies in the introduction of the ores can be safely restricted to the granite, which has already been described. The widespread effects of the granite upon the schists, the abundance of pegmatite and quartz veins, and the local contact zones show that it was competent to set up the necessary circulations concerned with the collection and precipitation of the zinc. Its intrusion seems to have been largely by upward stoping, during which gases and heated solutions were given off in abundance and permeated the roof of Grenville rocks.

There is no direct evidence as yet to indicate the sources of the zinc. The metal may have existed in the limestones in small but sufficient quantities to account for the present deposits, particularly as the concentration was effected before the strata had been greatly wasted by erosion.

SOME EXPERIMENTS BEARING ON THE SECONDARY ENRICHMENT OF MERCURY DEPOSITS.

T. M. Broderick.

I. INTRODUCTION.

The following experimental work is an investigation of the chemical relations of mercury intended to illustrate processes of its secondary enrichment. Considerable work has been done on the solubility of cinnabar in alkaline waters, and its precipitation from alkaline solutions, but the question of the solubility of cinnabar in acid solutions, and the conditions in which mercury is precipitated from such solutions has not hitherto been studied. There is considerable field evidence that several mercury minerals are secondary. Some of this evidence, as summarized by W. H. Emmons,[1] is as follows:

1. The occurrence of the chloride, oxychlorides, and oxide of mercury in the Terlingua district, Brewster County, Texas. Some of these minerals are rare and known only in this district. They are described by Hillebrand and Schaller.[2]

2. The occurrence of cinnabar associated with mercurial tetrahedrite. Lindgren[3] states that the cinnabar is the result of alteration of the mercurial tetrahedrite.

3. The occurrence of metacinnabar in the upper levels of mercury mines. Allen and Crenshaw[4] find that metacinnabar can not be precipitated from alkaline solution. Thus the finding of metacinnabar only near the surface is strong evidence that it was

[1] Emmons, W. H., "The Enrichment of Ores," U. S. Geol. Survey Bull. 625, in press.

[2] Hillebrand, W. F., and Schaller, W. T., "The Mercury Minerals from Terlingua, Texas," U. S. Geol. Survey Bull. 405, 1909.

[3] Lindgren, Waldemar, "Mineral Deposits," p. 801, 1913.

[4] Allen, E. T., and Crenshaw, J. L., "The Sulphides of Zinc, Cadmium, and Mercury; their Crystalline Forms and Genetic Conditions," *Amer. Jour. Sci.*, 4th ser., No. 202, Oct., 1912.

deposited from descending surface waters. Some of these occurrences of metacinnabar are as follows: It was found near the surface in the Knoxville district, Cal., and not in depth; it was also found in large amount in the Baker mine and in the upper levels of the Reed and Reddington mines.[5] Metacinnabar is crystallized in quartz and subsequent to it, in the New Almaden mines, Santa Clara County, Cal.[6]

4. The syntheses of Allen and Crenshaw show that cinnabar may be deposited by either acid or alkaline solutions. Thus it may be deposited from descending acid surface waters. That cinnabar is sometimes secondary is suggested by the following field evidence. At the Reddington mine, Cal.,[7] cinnabar coats metacinnabar, suggesting that the metacinnabar has changed into the more stable cinnabar. In a tunnel long in disuse, in the New Idria mine, Fresno County, Cal., Becker,[8] found a small seam of cinnabar in a coating of epsom salts and other secondary minerals, deposited since the mine was opened.

Field evidence shows that there is solution and redeposition of mercury in natural waters. The experimental work discussed below was undertaken to ascertain the nature of the water that will dissolve it and the means by which it may be precipitated.

II. THE CHEMISTRY OF MERCURY AND ITS COMPOUNDS.

In the periodic system mercury is grouped with zinc and cadmium. However, in many respects it is more like the members of the preceding group, containing copper, silver, and gold. In the air mercury behaves as a noble metal, that is, it does not oxidize spontaneously. However, mercury has an appreciable vapor pressure, and so must be soluble to some extent in water. In fact, water standing in contact with mercury, assumes poisonous properties.[9] Like copper it enters two series of compounds, the

[5] Becker, G. F., "Quicksilver Deposits of the Pacific Coast," U. S. Geol. Survey, Mon. 13, pp. 284, 368; 1888.

[6] Melville, W. H., *Am. Jour. Sci.*, Vol. 40, p. 291, 1890.

[7] Becker, G. F., *op. cit.*, p. 285.

[8] Becker, G. F., *op. cit.*, p. 307.

[9] Ostwald, "Principles of Inorganic Chemistry," translated by Findlay, p. 669.

mercurous, where it is univalent, and the mercuric, where it is bivalent. The mercurous halides are insoluble in water and are decomposed by light, though not as rapidly as the silver halides. Mercurous sulphate is very sparingly dissolved in water. At 25° C. it is decomposed in water, forming a basic salt. Mercuric chloride, or corrosive sublimate, is soluble in water. At 20°, the solubility is 7.4 parts to 100 parts of water. The solution is acid to litmus. Mercuric chloride solutions decompose very slowly in the dark to form mercuric oxide, chlorine and hydrochloric acid, and in the light, to form mercurous chloride and hydrochloric acid. It can be reduced by various reagents to the insoluble mercurous chloride. Mercuric sulphate, in contact with water, immediately hydrolyzes to an insoluble yellow basic salt. The oxides of mercury are formed by adding bases to the solutions of the mercurous and mercuric salts. The black mercurous oxide is unstable, and under influence of light or gentle heat, is decomposed into the red mercuric oxide and mercury. No carbonates of mercury are known. Alkali carbonates precipitate from mercuric solution red brown basic salts which are unstable in nature. From mercuric chloride solution the precipitate has the formula $HgCl_2(HgO)_2$. There are two crystalline sulphides of mercury, both having the formula HgS. One is red and occurs in nature as cinnabar; the other is black, occurring as metacinnabar. From acid solutions of mercuric salts, the amorphous black sulphide HgS, is precipitated by H_2S. Allen and Crenshaw treated this with alkali sulphide solutions and found that it was readily changed over to the more stable red form.[10]

III. SOLUBILITY OF CINNABAR.

The solubility of HgS in water is 12 parts in one hundred million. Cinnabar is soluble in alkali sulphide waters and is slowly attacked by natural alkaline solutions.[11]

[10] Allen, E. T., and Crenshaw, J. L., "The Sulphides of Zinc, Cadmium, and Mercury; their Crystalline Forms and Genetic Conditions," *Am. Jour. Sci.*, 4th ser., No. 202, Oct., 1912, p. 341.

[11] Grout, F. F., "On the Behavior of Cold Acid Sulphate Solutions of Copper, Silver, and Gold with Alkaline Extracts of Metallic Sulphides," ECON. GEOL., Vol. 8, p. 427, 1913.

In order to determine the solubility of cinnabar in waters such as are present in the oxidizing zone of ore deposits, the following experiments were made. One gram portions of cinnabar, 40 to 80 mesh, were left in contact with solutions as follows:

20 c.c. $1/20\,N\ H_2SO_4$ + 1 gram cinnabar,
20 c.c. $1/20\,N$ HCl + 1 gram cinnabar,
20 c.c. $1/20\,N\ H_2SO_4$ + $1/20\,N\ Fe_2(SO_4)_3$ + 1 gram cinnabar.

In six weeks' time the solutions were tested for mercury, which was found to be present only in the HCl solution. This result is to be expected, since the mercuric sulphate is hydrolyzed in contact with water, to an insoluble basic salt and the mercurous sulphate has a solubility of but 58 parts in one million. On the other hand the mercuric chloride is very soluble. These experiments were repeated, using more concentrated acids. The same results were obtained. The cinnabar dissolved only in the HCl. Nascent chlorine attacks the cinnabar even more readily. Powdered cinnabar and pyrolusite were treated by a dilute HCl solution. The solution showed large amounts of mercury in a short time. These results show that transportation of mercury in sulphate waters is probably ineffective, but is very likely to occur in arid regions where chloride waters are common. Thus the possibilities of secondary enrichment of mercury appear to be limited, for sulphate waters do not dissolve cinnabar.

IV. EXPERIMENTS ON THE PRECIPITATION OF MERCURY FROM SOLUTION.

Having shown experimentally that cinnabar goes into HCl solution, it is desirable to investigate the precipitation of mercury from cold acid waters. The gangue minerals common in mercury deposits are limited. Quartz, chalcedony, opal, calcite, marcasite, and pyrite are the most common. Stibnite, the sulphides of arsenic, and chalcopyrite are often present. Organic matter is present in some of the deposits.

Experiments were made with solutions of the mercurous sulphate and mercuric chloride. Some of the common sulphide minerals were left in contact with these solutions. It was found that the sulphate solution was too weak to be used for satisfactory experimentation. Its solubility is but 58 parts in one million. Experiments with the chloride solution were made under the following conditions. Twenty cubic centimeters of normal HCl solution were added to one cubic centimeter of concentrated $HgCl_2$ solution for each test. The solutions were placed in small bottles and about ½ gram of various sulphides, sifted through an 80-mesh sieve, added to them. The bottles were then stoppered and set away for a week. Similarly, other tests were prepared with the same reagents, except that 20 cubic centimeters of water was added instead of the 20 cubic centimeters of normal HCl. After standing a week, the solutions were filtered, and the insoluble matter tested for mercury. The results were as follows: The solutions, both acid and neutral, in contact with alabandite and pyrrhotite, gave up much of their mercury. It would be expected, of course, that the alabandite and pyrrhotite, in contact with HCl, would readily precipitate mercury as the sulphide. The insoluble matter from the bottles in which chalcopyrite and stibnite were left in contact with the mercuric chloride solution, both acid and neutral, showed that some mercury had been precipitated. Realgar, pyrite, or marcasite, however, had no effect in precipitating mercury, either in neutral or acid solutions. Of these sulphide minerals the only ones common in mercury deposits are chalcopyrite, pyrite, realgar, marcasite, and stibnite.

In order to find what effect reducing gases, such as might emanate from the organic matter which is present in many mercury deposits, would have, illuminating gas consisting principally of methane, hydrogen, and carbon monoxide, with some acetylene, benzene, and unsaturated hydrocarbons, was bubbled through a mercuric chloride solution. Almost immediately a white curdy precipitate formed, which was probably the mercurous chloride, calomel. It was filtered off, washed free from mercuric chlo-

ride, and washed back into a clean test tube. After shaking to get it into suspension, hydrogen sulphide was passed in. The white mercurous chloride immediately was blackened, HgS replacing the HgCl. This reaction requires the setting free of mercury, viz.:

$$2HgCl + H_2S = HgS + Hg + 2HCl.$$

Mercuric chloride solution was left in contact with finely powdered calcite. In a few days the mercury had almost completely precipitated. The color of the precipitate varied in different experiments, from yellow brown, through red brown to black. The precipitate was filtered, washed, and tested for mercury and chlorine, both of which were present. Inasmuch as the fixed alkali carbonates precipitate a red brown oxychloride from mercuric chloride solution, it is supposed that the precipitate with calcium carbonate is similar in composition. When the same experiment was tried with some $FeSO_4$ added, the precipitate after a few days was white, contained chlorine, was insoluble in HCl, and turned black when ammonia was added.

This experimental work on precipitation of mercury shows:

First. That mercury can be precipitated as a sulphide from both acid and neutral mercuric chloride solutions, by reaction with certain sulphides. One of these sulphides is stibnite, which is common in mercury deposits. It is possible that secondary mercury sulphide deposits were formed in this manner.

Second. Reducing gases and H_2S from organic matter in surrounding rocks may cause the precipitation of calomel, metacinnabar, and metallic mercury from descending chloride solution. The composition of kleinite, an oxychloride found in the Terlingua district, suggests the action of organic matter, in that it contains nitrogen.

Third. Calcite and ferrous sulphate form precipitates of the nature of rare minerals of the Terlingua district, such as terlinguaite and eglestonite, the oxychlorides; calomel, the chloride; and montroydite, the oxide. Significant is the fact that these minerals are all found associated with calcite, in fact deposited

on calcite crystals, and that some of them are stained red with iron.[12]

V. SUMMARY.

Secondary enrichment of metallic ore deposits consists essentially of solution of the ore in acid oxidizing waters, downward transportation, and precipitation by some agency, in depth. Field evidence points to the fact that there has been some enrichment in mercury deposits. The experiments outlined in this paper are attempts to elucidate the chemistry of the process. The easy solution of cinnabar in chloride waters was proved to be possible. Sulphate waters do not appreciably dissolve cinnabar. The secondary mercury minerals as seen in the field are metacinnabar, cinnabar, native mercury, the oxychlorides, the chloride, (calomel), and the oxide. Contact of chloride waters with certain sulphides precipitates mercury as sulphide. Reducing gases and H_2S, from organic matter, would precipitate the chloride, sulphide and native metal from chloride solution. Contact with calcite precipitates the oxychlorides and, if $FeSO_4$ is present, calomel is formed by reduction. With calcite as a gangue mineral, mercury could not be carried down very far. The native metal may be formed from the decomposition of the less stable minerals, such as the chloride or oxide. In fact it is found in these minerals in minute globules.[13]

Thanks are due Dr. W. H. Emmons, who outlined this work, and made suggestions during its progress.

[12] Hillebrand, W. F., and Schaller, W. T., "The Mercury Minerals from Terlingua, Texas," U. S. Geol. Survey Bull. 405, 1909.

[13] Hillebrand, W. F., and Schaller, W. T., *op. cit.*

WOOD TIN IN THE TERTIARY RHYOLITES OF NORTHERN NEVADA.[1]

ADOLPH KNOPF.

Tin ore has recently been found in northern Lander County, Nev. The stanniferous mineral is wood tin, occurring in narrow veinlets, traversing a series of rhyolite lavas of middle Tertiary age. The wood tin of these deposits is the first recorded occurrence of this mineral in place in the United States. To point out the hydrothermal origin of the deposits, the association of an unusual number of varieties of silica with the wood tin, and certain features of colloidal deposition that are strikingly exemplified by the deposits, is the purpose of this paper.[2]

THE RHYOLITE COUNTRY ROCK.

The rhyolites that enclose the veins are markedly porphyritic, the phenocrysts forming nearly half the bulk of the rocks. Quartz and sanidine dominate, and oligoclase ($Ab_{70}An_{30}$) occurs sporadically. Ferromagnesian minerals were rare and apparently consisted in the main of hornblende, now pseudomorphously altered to hematite. The rhyolites are rather porous and lithophysal; they commonly show flow-layering and in places are flow-brecciated; in short, they bear abundant evidence that they consist of a superposed succession of lava flows. According to W. H. Emmons[3] they are the oldest Tertiary lavas in this part of Nevada and their eruption probably began early in Miocene time.

The following partial analysis shows clearly the siliceous, alkalic character of the rhyolites:

[1] Published with the permission of the Director of the U. S. Geological Survey.

[2] The general geology of the deposits is described in "Tin Ore in Northern Lander County, Nev.," U. S. Geol. Survey Bull. 640-G, 1916.

[3] A reconnaissance of some mining camps in Elko, Lander and Eureka counties, Nev., U. S. Geol. Survey Bull. 408, p. 31, 1910.

PARTIAL ANALYSIS OF RHYOLITE FROM LANDER COUNTY, NEV.

(A. A. Chambers, analyst.)

SiO_2	76.25
CaO	.44
Na_2O	4.05
K_2O	5.18

THE TIN-BEARING DEPOSITS.

The tin-bearing veinlets traversing the rhyolites are narrow, but at some places enough veinlets occur to form stringer lodes. The stanniferous mineral is exclusively wood tin, which is inclosed in stringers, generally an inch or so wide, associated with specular hematite, chalcedony, lussatite, tridymite, and opal; the vein-forming minerals are generally limited to the stringers, but locally the adjoining rhyolite has been replaced by wood tin, hematite, and the various silica minerals. The groundmass has been wholly replaced but the phenocrysts of quartz and feldspar have remained intact.

Specular hematite is abundant in the stanniferous veinlets and is intergrown with all the other minerals present. It is embedded in the wood tin in amounts ranging from microscopic particles to masses that make up the larger part of the wood-tin individuals. Chalcedony seems to the unaided eye to be the dominant gangue mineral in the veinlets, but under the microscope a large part of the fibrous silica is found to correspond closely to lussatite.

The name lussatite was given by Mallard[4] to a fibrous variety of silica, whose average refractive index is 1.446, whose birefringence is somewhat less than that of quartz, and whose fibers show positive optical elongation—properties that serve to distinguish it easily from chalcedony. As seen under the microscope the lussatite in the tin-bearing veinlets is of globular habit and in parallel light resembles the opal occurring with it: it has the same high relief, light brownish color, and well-marked concentric structure, as may be seen in Fig. 35. Between crossed nicols it

[4] Mallard, E., "Sur la lussatite, nouvelle variété minérale cristallisée de silice," Soc. franc. de Mineralogie, Bull., Vol. 13, pp. 63–66, 1890.

shows a finely fibrous spherulitic structure, like chalcedony (Fig. 36) but the elongation of the fibers is positive, its birefringence, as determined by means of the interference chart, is about 0.006. The refractive index was found by the oil immersion method to be approximately 1.45. The mineral is therefore identified as lussatite. All stages are represented between completely isotropic

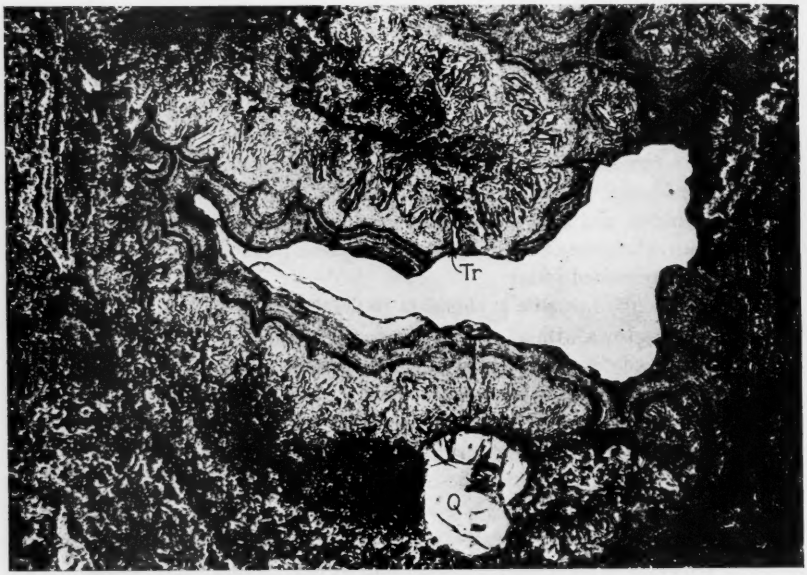

FIG. 35. Sussatite surrounding a vug in silicified rhyolite. *Tr* indicates one of the many plates of trydymite enclosed in it; *Q* indicates a quartz phenocryst residual from the original rhyolite. Parallel light; magnification, 32 diameters. Modoc prospect.

opal and the most strongly birefringent spherulites, and there can be little doubt that the lussatite has resulted from the crystallization of opal.

Where chalcedony and lussatite occur associated together, they

are invariably sharply individualized and there is no gradation between them, nor are there any features that even suggest the possibility of such a gradation. The chalcedony is a clear limpid mineral, in parallel light resembling quartz; its refractive indices,

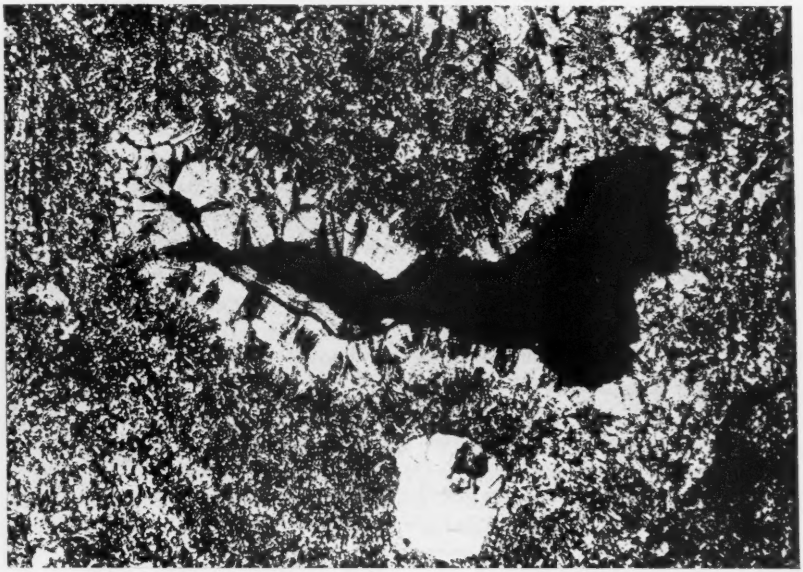

FIG. 36. Same, with nicols crossed, showing the radial fibrous structure of the lussatite.

as determined by immersion in oils, slightly exceed 1.53, however, The distinction between lussatite and chalcedony is in places very striking, especially in vicinity of plates of hematite. Each plate of hematite is completely surrounded by a layer of lussatite, whose light brownish tint and strong relief sets it off sharply from the embedding matrix of colorless chalcedony. Slavik[5] has

[5] Slavik, F., "Ueber die wahrscheinliche Identität von Lussatite und Tridymit," *Centralbl. Mineralogie*, p. 690, 1901.

suggested that lussatite is a fibrous form of tridymite in which the fibers are elongated parallel to the *c-axis*. This suggestion has much to commend it, but the birefringence of lussatite—about three times that of tridymite—militates against its acceptance. Whatever may be the relation of lussatite to the other crystallized varieties of silica, it appears certain that in the Nevada occurrence it has resulted from the crystallization of opaline silica.

The opal associated with the wood tin is a white or creamy-white variety; its refractive index is approximately 1.448, though adjoining layers are of slightly different indices. A noteworthy constituent of the gangue is tridymite; in places it occurs as a macroscopic component in aggregates of thin plates, but as a rule is only recognizable microscopically. In places well-defined plates of it are inclosed in lussatite. Although silica minerals are so abundant in the tin ore, quartz, though common as a phenocrystic relict, is rare as an epigenetic mineral, occurring in fact only in microscopic amount.

The wood tin invariably shows the characteristic concentric banding that resembles the annual growth-rings of wood. In color it ranges from dark reddish to brown, and differences in shade of this order generally determine the banding, which, however, is not equally marked in all specimens. The wood tin is generally in globular masses, or in the different modifications of this form that are termed botryoidal, mammillary, and reniform. As seen on polished surfaces and in thin sections, the particles of wood tin commonly contain nuclei of hematite. Some of these nuclei are surrounded by opal, then by hematite, and then by wood tin. Hematite, however, forms not only the nuclei but is also scattered abundantly throughout the wood tin.

ANALYSIS OF WOOD TIN FROM LANDER COUNTY, NEV.
(A. A. Chambers, analyst.)

SnO_2	85.14
SiO_2	1.03
Fe_2O_3	13.42
MnO	.02
H_2O-	.20
H_2O+	.05
	99.86

An analysis of a nugget of wood tin is given in the accompanying table. The specimen was selected because free from inclusions of hematite and because of its homogeneity.

The analysis shows that the wood tin is highly ferriferous, comparable in this respect to specimens of Mexican wood tin analyzed by Genth.

Under the microscope much of the wood tin proves to be opaque. The banding is seen to be due principally to the alternation of opaque or nearly opaque bands with fairly translucent bands. The translucent bands are deep yellowish brown, and react on polarized light, giving a shadowy extinction, suggestive of an ill-defined radial fibrous structure. What is the origin of the banding? Has it resulted from the growth of the wood tin by the periodic addition of new layers of differing composition, or is it a diffusion effect—the Liesegang phenomenon of rhythmic precipitation?[6] The complexity of the banded structures and the general independence of these structures to the walls of the veinlets harmonizes best with the hypothesis that the banding is a diffusion effect. Each particle of wood tin is characterized by its own peculiar banded pattern. Under the microscope the banding is found to be intimately related to the included plates of hematite. The banding completely envelops the inclusions and forms a series of concentric circles and ellipses around them. If the banding were due to "crustification," however, each band would be merely deflected by an inclusion and would envelop the inclusion only part way round, instead of completely surrounding it. This is believed to be a valid criterion by which banding due to the Liesegang phenomenon may be distinguished from banding due to crustification.

The inclusions evidently acted as nuclei from which some compound diffused centrifugally and induced rhythmic precipitation within the stannic oxide in which they were imbedded. If this explanation is correct, then in accordance with the known phenomena of rhythmic precipitation, the banding should be most

[6] Liesegang, R. E., "Geologische Diffusionen," pp. 81–159, 1913. Review in ECON. GEOL., Vol. 8, pp. 803–806, 1913.

closely spaced near the nuclei and progressively wider spaced at increasing distances from them; and this relation is in fact found to be generally true. These facts are believed to prove conclusively that the ultimate origin of the banding is due to rhythmic precipitation in a medium of colloidal stannic oxide.

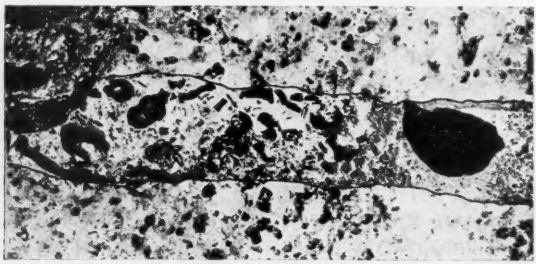

FIG. 37. Veinlet containing wood tin; the walls are indicated by the inked lines. The black particles within the veinlet are wood tin and the gray are hematite; the black particles without the veinlet are the quartz phenocrysts of the enclosing rhyolite. Enlarged 1⅓ diameters. Modoc prospect.

Inspection of Figs. 37 and 38 will show the diverse form characteristic of the particles of wood tin and how remarkable some of these forms are. There are angular particles suggestive of post-mineral brecciation; there are particles shaped like broad interrogation marks and like broken annuli. These queer structures and the apparent post-mineral brecciation are interpreted here as having resulted from the bursting of colloidal membranes by osmotic forces, as in the well-known example of the bursting of Traube cells. If a drop of concentrated copper sulphate solution is placed in a dilute solution of potassium ferrocyanide, it will surround itself with a membrane of copper ferrocyanide. The membrane thus formed is permeable only to water, whose continued ingress into the cell soon causes the membrane to burst. At the point of rupture the cell immediately heals, however, by forming a new membrane of copper ferrocyanide, and thus the cell grows for some time by alternate rupture and repair. That

certain seemingly brecciated agates very probably originated in an analogous way has been clearly shown by Liesegang.[7]

That the wood tin was deformed and ruptured while still in the plastic colloidal state is strongly indicated by the broken ring-like forms already mentioned and is proved beyond reasonable doubt by the deformation shown by some of the layers that

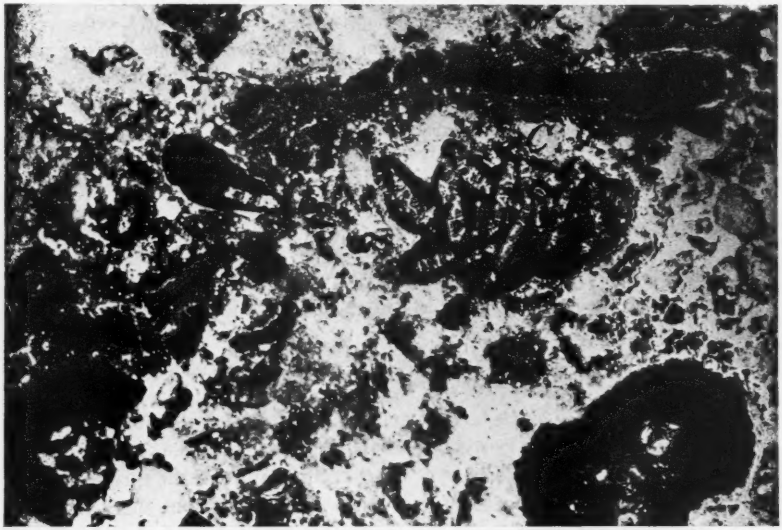

FIG. 38. Details of same veinlet shows the remarkable shapes of the particles of wood tin, which indicate that the wood tin was deformed while still a plastic colloid. *C* shows a complex cellular growth of wood tin, whose interior is filled by hematite and subordinate opal.

formerly lined the walls of certain veinlets: they have been deformed so that they resemble the conventional diagram of an overturned anticlinal fold. The complex, many-walled cell shown below *C* in Fig. 38, is doubtless an unusually well-developed

[7] Liesegang, R. E., "Ein Membrantrümmer-Achat," *Centralbl. Mineralogie*, pp. 65–67, 1912.

analogue of a Traube cell that has grown to considerable dimensions by alternate rupture and repair. The interior of the cell is filled with hematite and a little accessory opal. High magnification shows that the exterior wall of the cell is broken slightly at a few places; it shows further that the outer wall and the numerous inner walls are all delicately banded parallel to their sides—a feature that can be reasonably accounted for only by the hypothesis of diffusional rhythmic precipitation previously advanced. Although these processes—rhythmic precipitation and the bursting of colloidal membranes of stannic oxide by osmotic forces—are clearly indicated by the wood tin occurring in the veinlets, their chemistry is yet obscure.

GENESIS OF THE DEPOSITS.

That the tin-bearing veins were deposited from aqueous solutions is shown by the presence of opal in them, and that these solutions were hot is indicated by the tridymite, a mineral which has been repeatedly synthesized in aqueous solutions at temperatures ranging from 300° to 400° C. According to Daubrée, however, tridymite occurs embedded in the hyalite opal that has formed in the pores of the Roman bricks altered by the hot springs of Plombiéres.[8] If Daubrée's identification of the mineral as tridymite is correct, it establishes that tridymite may be formed in nature as low as 73° C., the temperature of the springs of Plombiéres. From Daubrée's observations and Koenigsberger and Müller's[9] experiments, in which they found that 360° C. is the highest temperature at which they were able to synthesize opal (quartz, chalcedony, and tridymite being obtained with it at the same time), it follows that the stanniferous veinlets were formed at temperatures probably between 73° and 360° C.; and the presence of the specular hematite in the veinlets indicates that

[8] Daubrée, A., "Sur la presénce de la tridymite dans le briques zeolithiques de Plombiéres," *Soc. géol. France,* Vol. 4, 3d ser., p. 523, 1876; "Geologie experimentale," p. 195, 1879.

[9] Koenigsberger, J., and Müller, W. J., "Versuche über die Bildung von Quarz und Silikaten," *Centralbl. Mineralogie,* p. 371, 1906.

more likely they were deposited near 360° than near the lower limit. The stannic oxide separated from solution in the colloid state and subsequently, in part at least, has become crystalline; the ferric oxide was deposited mainly as a crystalloid (hematite) but partly as a colloid entangled with the stannic oxide; and the silica was deposited both as crystalloid and as colloid, but mainly as a colloid (opal) which has later crystallized to lussatite

THE RELATION OF THE TITANIFEROUS MAGNETITE ORES OF GLAMORGAN TOWNSHIP, HALIBURTON COUNTY, ONTARIO, TO THE ASSOCIATED SCAPOLITIC GABBROS.

W. G. Foye.

INTRODUCTION.

The Glamorgan gabbro laccolith is situated in the township of Glamorgan, Haliburton county, Ontario. It was first described by Professor F. D. Adams and Dr. A. E. Barlow in their memoir on the Haliburton-Bancroft Area.[1] The laccolith is eight miles long and two miles wide. It was intruded into the Grenville sediments, consisting of sandstones, shales, and limestones, before the period of the intrusion of the granites and nephelite syenites which form so distinct a part of this region. The geological map (Fig. 39) shows the distribution of the rock types.

SUMMARY.

The pneumatolytic gases given off by the granites and nephelite syenites at the time of their intrusion collected beneath the gabbro laccolith as a cover and, slowly penetrating it, effected the following results.

1. The iron carried by these gases was oxidized to titaniferous magnetite and deposited beneath the laccolith.

2. The chlorine and other gases thus liberated scapolitized the overlying gabbro and recrystallized it.

THE GLAMORGAN GABBRO.

The original gabbro occurs very sparingly in the altered body, and is found especially at the lower contact of the laccolith northwest of Drag Lake.

[1] Geol. Surv. Can., Memoir No. 6 (1910), pp. 153–156.

Macroscopic Description.—The gabbro is a medium-grained rock, dark-olive-green, consisting of augite, plagioclase, and accessory apatite. The augite crystals are 5–10 mm. long and 3 mm. wide and show a slight tendency to diabasic structure. The interstitial spaces are filled with a fine granular, allotriomorphic plagioclase which is oily, olive-green in color.

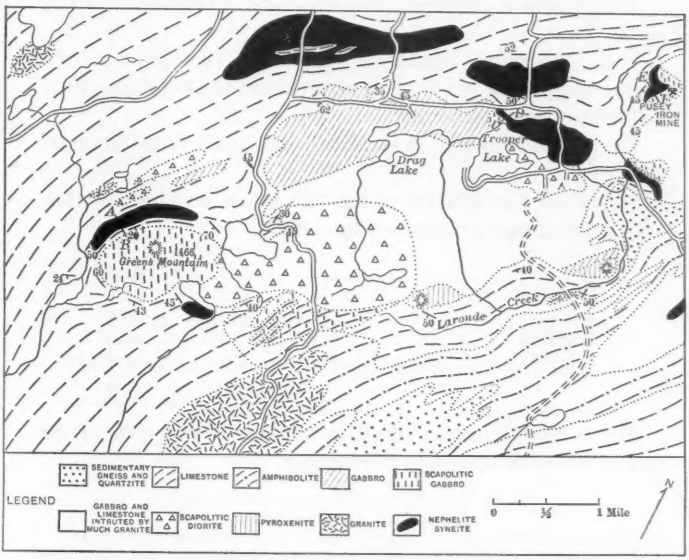

FIG. 39. Geological map showing distribution of rock types.

Microscopic Description.—Under the microscope the rock is seen to be composed of augite, hornblende, and andesine with accessory titaniferous magnetite and apatite. The rock shows the effect of shearing; the albite twin lamellæ of the feldspars are curved and also the cleavage lines of the augite.

The *augite* is light olive-green in color, extinguishes at 45°, approximately, between cross nicols and often shows twinning on the front pinacoid. It has altered in large part about its edges to

hornblende. The augite crystals are sometimes idiomorphic showing the forms (010) and (110). The augite is filled with myriads of minute inclusions oriented parallel to its cleavage. These are olive-green under the high power and appear to be the beginnings of the transformation of augite to hornblende since they cease to exist in the hornblende derived from the augite.

The *feldspar* is andesine ($Ab_{65}An_{35}$) and is twinned according to the albite, carlsbad, and pericline laws.

The *hornblende* is pleochroic olive-brown, olive-green to yellow. Absorption $z > y > x$. It extinguishes at 18–20° on (010) and is negative in character.

The *apatite* is usually in small laths but again forms granular bunches.

A Rosiwal measurement of the rock shows it to have the following percentage composition by weight.

Augite	19.52
Hornblende	44.36
Andesine	22.65
Magnetite	12.23
Apatite	1.24
	100.00

The hornblende which seems to form so large a part of the rock is in reality secondary after augite.

CHEMICAL COMPOSITION.

The analysis of the type gabbro is as follows:

	Per Cent.
SiO_2	47.90
TiO_2	2.00
Al_2O_3	13.76
Fe_2O_3	0.42
FeO	6.43
MgO	7.27
MnO	0.11
CaO	16.76
Na_2O	2.27
K_2O	0.66
P_2O_5	0.06

	Per. Cent.
S	0.11
Cl	trace
CO_2	1.10
H_2O	0.80
	99.65

The norm calculated from the analysis is:

	Per Cent.
Orthoclase	3.89
Albite	14.68
Anorthite	23.63
Nephelite	2.56
Diopside	41.86
Olivine	4.13
Magnetite	.70
Ilmenite	3.80
Apatite	.31
Pyrite	.26
Calcite	2.50
	98.32
Water	.80
	99.12

Specific gravity at 20° C. = 3.038.

The position of the rock in the norm classification is:

Class III.	Salfemane
Order 5	Gallare
Rang 5	Kedabekose

THE GARNET-DIOPSIDE CONTACT ROCK.

At several places along both the upper and lower contacts of the laccolith, where the metamorphic forces were least active, the garnet-diopside contact rock, produced at the time of the intrusion of the primary gabbro, has been preserved.

Macroscopic Description.—The rock is reddish brown in color with a mottling of grayish green. It is composed almost entirely of massive, reddish-brown garnet with grayish-green diopside. It is very fine grained.

Microscopic Description.—Microscopically the rock is simple in composition. It consists of a reddish, clear garnet with greenish diopside and calcite. About three quarters of the rock

is garnet; the larger portion of the rest, diopside and calcite. The diopside is finely granular and is disseminated through the garnet. Some zoisite is also present.

THE PNEUMATOLYTIC ALTERATIONS OF THE GABBRO.

Sheet-like intrusions of rocks closely related to syenites are found at, or just below, the lower contact of the laccolith almost continuously along its northern border. The more striking results produced by these intrusions will be described.

GREEN'S MOUNTAIN.

North of Green's Mountain at the western end of the laccolith, the gabbro is related to other rock types as shown in the sketch (Fig. 40).

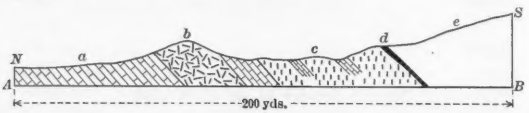

FIG. 40. *a*, limestone; *b*, nephelite syenite; *c*, red syenite with limestone; *d*, actinolite-scapolite rock; *e*, scapolitic gabbro.

The normal garnet-diopside contact rock disappears wherever the syenite is found beneath the gabbro and is replaced by an actinolite-scapolite rock consisting of calcite, scapolite, actinolite, diopside, and a little plagioclase. This rock is transitional into a scapolitic gabbro which forms the main mass of Green's Mountain. The scapolite contains amœboid forms of diopside as does also the actinolite. Blebs of calcite are found in all the minerals. The rock gives every indication of having undergone recrystallization.

CONTACT NORTH OF TROOPER LAKE.

North of Trooper Lake several small laccoliths of nephelite syenite have been intruded into the limestone. One of these lies immediately beneath the gabbro body. To the west of the nephelite syenite a cross section would show the relations in Fig. 41.

Immediately beneath the gabbro there is a sheet-like body of hornblende and graphite, in about equal proportions, mingled in a glanular matrix of calcite. The hornblende is pleochroic, faint blue in color and is massed in a felty aggregate. Limestone separates this sheet from the gabbro.

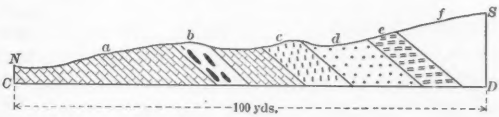

FIG. 41. *a*, limestone; *b*, hornblendite with graphite; *c*, garnet-hornblende rock with albite and a little nephelite; *d*, quite basic hornblende-nephelite rock; *e*, scapolitic pyroxenite; *f*, scapolite gabbro.

The gabbro and the nephelite syenite apparently have a transitional contact, due to the fusing of the gabbro by the nephelite syenite. The elements of the gabbro were redistributed and the rock was recrystallized as a "geflecter" gabbro having a lower silica content than the primary type. Fifty feet from the contact the "geflecter" gabbro is replaced by the type scapolitic gabbro such as occurs in Green's Mountain. The rock succession at this locality is entirely analogous to that near the Pusey Iron Mine.

THE PUSEY IRON MINE.

The sketch (Fig. 42) indicates the rock types occurring beneath the Pusey Iron Ore deposits. The mine has never been worked

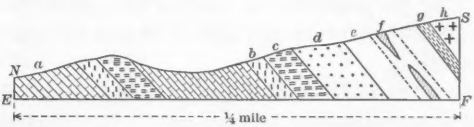

FIG. 42. *a*, limestone; *b*, hornblenditic nephelite syenite; *c*, monmouthite; *d*, scapolitic pyroxenite; *e*, covered in part, outcrops of gabbro; *f*, Pusey iron ore; *g*, amphibolite; *h*, scapolitic gabbro.

extensively. Adams and Barlow[2] state the following facts concerning the deposit.

[2] Pusey Iron Mine. See Adams and Barlow, Memoir 6, Geol. Surv. Can., "Geology of the Haliburton and Bancroft Areas, Ontario," p. 353.

"A large deposit of granular, black magnetite ore forms a ledge, or succession of ledges, rising to a height of 80 or 100 feet above the general level of the district. It is exposed for a length of 1,800 feet and has a width from 70 to 198 feet."

The following is the result of an analysis made by F. J. Pope:

	Per Cent.
Fe_2O_3	39.27
FeO	21.73
MnO	0.37
MO	0.27
CoO	0.07
Al_2O_3	4.61
SiO_2	10.77
P_2O_5	0.02
S	0.11
TiO_2	13.52
V_2O_5	0.52
MgO	2.34
BaO	0.07
CaO	4.84
Na_2O	0.31
K_2O	0.24
Moisture	0.44
	99.50

The original rock at the Iron Mine was a gabbro consisting of acid labradorite ($Ab_{45}An_{55}$) and augite. Twelve feet below the main ore deposit the original rock has been altered, (1) by the uralitization of the augite, (2) by the kaolinization of the feldspar, (3) by the production of reaction rims about the feldspar and augite, and (4) by the introduction of iron ore, apatite, and a soda hornblende.

These processes of alteration were probably closely related and occurred at approximately the same time. The alteration of the several minerals will be discussed in order.

The *feldspar* is twinned on the albite, carlsbad, and pericline laws. The beginning of alteration is marked by the introduction of myriads of minute blebs of blue hornblende and needles of apatite along its twinning planes. Again, in irregular cross veinlets, a brown biotite is developed in minute flakes. As the proc-

ess continues the minute hornblende-blebs sometimes unite to form euhedral crystals and the feldspar is replaced by a kaolinized mass filled with irregular crystals of hornblende. In other cases the feldspar is recrystallized into a fine mosaic at the center of which amœboid bits of hornblende unite to form an irregular network.

The *augite* is entirely replaced by olive-green hornblende. The reaction rims about the larger grains of this mineral are uniform. The olive-green hornblende becomes frayed at its edges into an irregular network filled with granular feldspar. The granular feldspar forms a zone about the hornblende grain within which large euhedral apatite crystals occur. Without this zone is a fringe of radiating crystals of blue hornblende.

In certain cases the apatite is enclosed within the ore (which has a border of brown biotite). Again the brown biotite zone is lacking and the olive-green hornblende is in juxtaposition with the ore. Sometimes the ore is entirely lacking and the biotite forms a rosette with a surrounding zone of hornblende. The apatite in the latter case remains at the center of the rosette. The microphotographs (Figs. 43 and 44) show certain cases of the alteration just described.

The reaction rims about the *iron ore* vary. A bit of pleonaste is often found at the center of the ore grain. Usually about the grain, brown biotite is formed in radiating plates. Within the biotite zone, apatite crystals are often found, while a fringe of brown hornblende surrounds it. The outer edge of the brown hornblende zone is usually bordered by a narrow zone of blue hornblende.

The rock associated with the ore deposit differs from that twelve feet below in that it contains, in the section, a considerable amount of rose-colored augite. The iron ore occurs as irregular grains against the feldspar.

The rock, twenty-five feet above the ore body, is very dark green in color. Under the microscope it appears finely granular but in the hand specimen the grouping of the femic minerals between irregular grains of calcite gives it a coarse-grained appearance.

The rock is composed of pyroxene, olive-green hornblende, andesine ($Ab_{60}An_{40}$), calcite, scapolite, and titaniferous magnetite.

FIG. 43. Reaction rim of biotite about iron ore and apatite. Also feldspar impregnated with hornblende microcrysts. (× 60.)

The *feldspar* has been altered to *scapolite* and both of these minerals have decomposed to muscovite and kaolin.

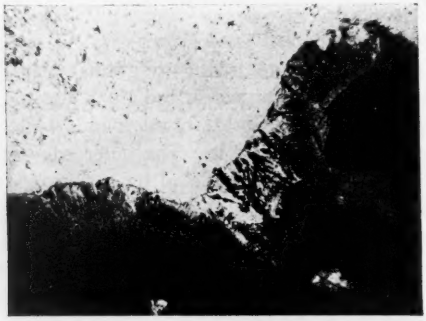

FIG. 44. Reaction rim consisting of vernicular forms of hornblende extending from the iron ore into the feldspar. (× 60.)

The *pyroxenes* are apparently of two generations. The first is a violet-colored augite, the last an apple green or colorless diopside.

These minerals have reaction rims of olive-green hornblende against the feldspars.

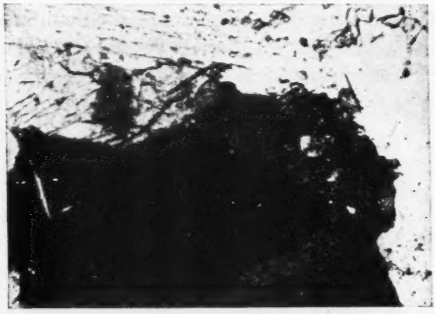

FIG. 45. Reaction rim of hornblende about iron ore. The triangular marking in the ore is a bit of pleonaste. (× 50.)

Minute blebs of *calcite* are present in the minerals, and large masses of it occur at intervals through the rock.

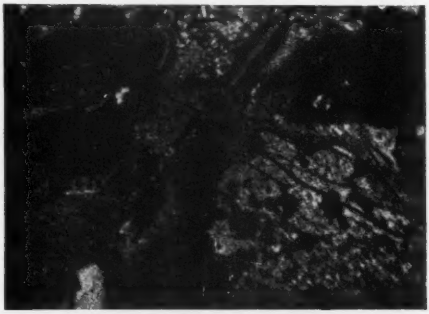

FIG. 46. Microphotograph showing the scapolitization of the labradorite of the Glamorgan gabbro.

The rocks above this horizon are schistose amphibolites overlain by scapolitic gabbros. The iron ore body therefore is sep-

arated from the main mass of the gabbro by amphibolites and scapolitic rocks carrying calcite.

The association of pleonaste with iron ore and the reaction rims about the ore recall the structure of the titaniferous magnetite of Mine Hill, Rhode Island. Professor C. H. Warren[3] summarizes the mineralogical changes which produced the reaction rims as follows:

"The particular chemico-mineralogical changes which may be noted here are: (1) The formation of a blue, soda-iron or soda-aluminum amphibole molecule from the soda (and alumina?) of the plagioclase and from the ferric iron of the ilmenite. The brown variety may well be due to the entrance into the molecule of a different proportion of ferric iron and titanium. (2) The formation of biotite, for which both ferrous and ferric iron were derived from the ilmenite, alumina and alkalies from the ilmenite, alumina and alkalies from the feldspar, and perhaps magnesia from the augite or fibrous hornblende. The titanium, originally combined with the iron used up in the formation of the biotite, probably also enters into this latter mineral: at all events leucoxene or other titanium bearing minerals are absent."

"The water given off by the rock on intense ignition reacts acid, indicating the presence of fluorine. This is probably present in the hornblende and biotite and it is possible that it may have originally been derived from emanations from the adjoining granite intrusions, which are believed to be later than the gabbro and are known to contain considerable fluorine in places. The effect of even an exceedingly small amount of fluorine in changes like those recorded here would be unquestionably great and is worthy of consideration."

PETROGRAPHIC DESCRIPTIONS OF THE SCAPOLITIC AND "GEFLECKTER" GABBROS.

Scapolitic Gabbro.

Macroscopic Description.—The typical scapolitic gabbro, as it occurs in Green's Mountain, is a dense greenish, pepper-and-salt colored rock, mottled with areas, two or three centimeters across, of white, translucent, sugary feldspar. The feldspar is in granules 5–6 mm. in diameter and is distributed irregularly in the felty

[3] C. H. Warren, *Am. Journ. Sci.*, 4th Series, Vol. 26 (1908), pp. 474–475.

mat of augite and hornblende crystals which forms the ground mass of the rock. The augite and hornblende are in crystals 2–3 mm. long and 1–2 mm. wide.

The rock has a compact texture, breaks with great difficulty with a conchoidal fracture, is heavy, and is rarely decomposed to any extent.

Microscopic Description.—The thin section shows the following minerals in the given proportions by weight.

	Per Cent.
Labradorite	19.08
Scapolite	7.37
Augite	46.03
Hornblende	27.04
Iron Ore	0.48
	100.00

The *feldspar* is labradorite, having the composition of approximately $Ab_{50}An_{50}$.

Scapolite occurs between the grains of feldspar, or feldspar and augite, in amœboid forms which follow the irregular outlines of the grains of feldspar and augite. Again the feldspar is found altering to scapolite. This alteration begins along the planes of the carlsbad or pericline twinning and so progresses into the crystal.

The *augite* is colorless in thin section, and extinguishes at 35° to its cleavage. Minute blebs of a mineral like titanite are common in the augite. These are usually oriented parallel to the cleavage.

The hornblende is weakly pleochroic and is uralitic after the augite. Its optical properties relate it to actinolite.

The texture of the rock is allotriomorphic granular or poicilitic.

Chemical Composition.—The chemical composition of the scapolitic gabbro is shown by the following analysis.

	Per Cent.
SiO_2	47.96
TiO_2	0.92
Al_2O_3	12.91
Fe_2O_3	0.36
FeO	5.34
MgO	10.93
MnO	0.07
CaO	17.76
Na_2O	1.55
K_2O	0.63
P_2O_5	0.05
S	0.13
Cl	0.07
CO_2	0.72
H_2O	0.55
	99.95

The norm calculated from the analysis is:

	Per Cent.
Orthoclase	3.34
Albite	5.76
Anorthite	26.41
Nephelite	4.26
Diopside	45.21
Olivine	9.73
Magnetite	.70
Ilmenite	1.67
Pyrite	.26
Apatite	.31
Calcite	1.60
	99.25
Water	.55
	99.80

Specific gravity at 20° C. = 3.155.

Its position in the norm classification is, therefore:

Class III	Salfemane
Order 5	Gallare
Rang 5	Kedabekose

"GEFLECKTER" GABBRO.

"Gefleckter" gabbros form layers from fifteen to twenty feet in thickness overlying the nephelite syenite bodies about the edge of the gabbro mass.

Macroscopic Description.—These rocks are dark, olive-green in color, with a few areas of bluish white scapolite. In large outcrops pinkish nodules occur in the rock which the microscope shows to be scapolite. The white areas are composed of sugary granules having a bluish tint like névé. The augite is anhedral and occurs in quite large granules, giving the rock a massive appearance.

Minute flecks of pyrrhotite are often present.

Microscopic Description.—The mode of the "gefleckter" gabbro is as follows:

	Per Cent.
Scapolite	24.27
Augite	44.19
Hornblende	27.94
Calcite	3.60
	100.00

This corresponds very closely to the scapolitic gabbro, if it is taken into consideration that the feldspar is here replaced by scapolite.

The *augite* is a colorless variety analogous to that in the scapolitic gabbro. It contains many blebs of calcite and is changing to uralitic hornblende.

The *hornblende* differs from that of the scapolitic gabbro. While the other was actinolite, this is pleochroic dark olive-green // z, green // y, and greenish yellow // x. It extinguishes at a small angle and is negative in character. While it is usually uralitic after the augite, it is often crystallized in hypidiomorphic crystals and is also found as graphic intergrowths in the augite.

The *scapolite* and calcite occur as irregular grains in the angular spaces between the augite crystals. Augite is sometimes found in graphic intergrowths with the scapolite. The scapolite is also found as a border about the calcite in contact with the hornblende.

The rock has a poicilitic texture.

The amount of hornblende present is greater than in the scapolitic gabbro and it is also a more complex variety. This may be explained by its association with the nephelite syenite.

The loss of scapolite or its segregation into nodular masses transforms this rock to a scapolitic pyroxenite or hornblendite,

according as the pyroxene has been partially or wholly altered to amphibole.

Chemical Composition.—The following analysis gives the chemical composition of the "gefleckter" gabbro.

	Per Cent.
SiO_2	43.96
TiO_2	1.80
Al_2O_3	13.72
Fe_2O_3	0.79
FeO	9.51
MgO	6.91
MnO	0.10
CaO	18.20
Na_2O	2.09
F_2O	0.96
H_2O	0.40
P_2O_5	0.07
Cl	trace
S	0.14
CO_2	1.00
SrO	trace
BaO	none
	99.65

The norm calculated from the analysis is:

	Per Cent.
Leucite	4.80
Nephelite	9.66
Anorthite	24.74
Diopside	44.17
Olivine	6.80
Akermanite	1.62
Magnetite	1.16
Ilmenite	3.50
Pyrite	0.17
Apatite	0.31
Calcite	2.30
	99.23
Water	0.40
	99.63

Specific gravity at 20° C. = 3.325.

Its position in the norm classification is:

Class III	Salfemane
Order 6	Portugare
Rang 5	Percalcic

THEORETICAL CONSIDERATIONS.

The Origin of the Scapolitic Rocks.

The question of the origin of scapolite in various rocks has been treated extensively. F. W. Clark states:[4]

"The scapolites, as shown by G. Tschermak, are mixtures of two end species—meionite, $Ca_4Al_6Si_6O_{25}$, and marialite, $Na_4Al_3Si_9O_{24}Cl$. These may be derived from anorthite and albite in accordance with the following empirical equations.

$$3CaAl_2Si_2O_8 + CaO = Ca_4Al_6Si_6O_{25},$$
$$3NaAlSi_3O_8 + NaCl = Na_4Al_3Si_9O_{24}Cl."$$

Clark suggests that the change of pyroxene to amphibole may furnish the lime for this reaction. The source of the chlorine is problematic. J. W. Judd[5] found liquid inclusions in feldspar containing minute cubes of sodium chloride. He argued, therefore, that dynamic metamorphism had caused the sodium chloride to react with the feldspar to produce scapolite. A. Lacroix[6] opposed this view, since at the same occurrence described by Judd (Odegården, Norway), as well as elsewhere (Pyrenees, Regårdshein), the feldspars contained no liquid inclusions and were not affected by dynamic metamorphism, yet had altered to scapolite. Lacroix[7] summarizes the occurrences of scapolite as follows:

"1. In volcanic rocks (bombs from Monte Somma),
"2. In pyroxene gneisses and associated serpentines,
"3. In eruptive rocks where they result from the transformation of the feldspar either by special metamorphic processes (veins of apatite in Norway) or by secondary action (nephelite syenite, diabase, etc.),
"4. In limestone where they arise from the contact effects of igneous rocks (contact of the Lower Silurian limestone of Brevig with nephelite syenite)."

C. H. Smyth, Jr.,[8] has described a gabbro from New York which was scapolitized, he believes, by chlorine introduced from

[4] F. W. Clark, U. S. G. S. Bull. 330, pp. 514–515.
[5] J. W. Judd, *Min. Mag.*, Vol. 8 (1889), p. 186.
[6] A. Lacroix, *Bull. Soc. Min. France*, Vol. 14 (1891), pp. 28–29.
[7] A. Lacroix, *Bull. Soc. Min. France*, Vol. 12 (1889), pp. 357–358.
[8] C. H. Smyth, *Jr. Am. Journ. Sci.*, 4th Series, Vol. 1 (1896), p. 273.

a foreign source. The only rocks near at hand capable of producing the effect are granites.

F. D. Adams and A. C. Lawson[9] have described a number of scapolitic rocks from Ontario which have apparently been scapolitized by apatite-bearing dikes similar to the Norway intrusives.

A study of a large number of specimens from the Glamorgan gabbro body has revealed the following facts:

1. The augite and feldspar of the scapolitic gabbros are similar to those of the original gabbro of the area.

2. The scapolite occurs as amœboid forms replacing the feldspar. (See microphotograph, Fig. 46.)

3. The scapolitic pyroxenites have a poicilitic texture and a "pflaster" structure indicative of recrystallization.

4. The pyroxenites are often altered to hornblendites due to the replacement of augite by blue hornblende.

5. The chemical analysis of the primary gabbro and the scapolitic variety shows that the actual change in composition is slight. Column I. gives the analysis of a scapolitic gabbro from Green's Mountain and Column II. the analysis of the primary gabbro.

	I.	II.
	Per Cent.	Per Cent.
SiO_2	47.96	47.90
TiO_2	0.92	2.00
Al_2O_3	12.91	13.76
Fe_2O_3	0.36	0.42
FeO	5.34	6.43
MgO	10.93	7.27
MnO	0.07	0.11
CaO	17.76	16.76
Na_2O	1.55	2.27
K_2O	0.63	0.66
P_2O_5	0.05	0.06
S	0.13	0.11
Cl	0.07	none
CO_2	0.72	1.10
H_2O	0.55	0.80
	99.95	99.65

6. The comparative Rosiwal measurements of the original gabbro, the scapolitic gabbro, and the "gefleckter" gabbro are as follows:

[9] F. D. Adams and A. C. Lawson, *Can. Record Sci.*, Vol. 3 (1888), p. 185.

	Original Gabbro,[10] Per Cent.	Scapolitic Gabbro, Per Cent.	"Gefleckter" Gabbro, Per Cent.
Andesine	22.65	19.08	....
Scapolite	....	7.37	20.96
Augite	19.52	46.03	46.92
Hornblende	44.36	27.04	29.01
Iron ore	12.23	0.48	....
Calcite	....	....	3.11
Apatite	1.24	....	....
	100.00	100.00	100.00

It is believed the scapolitization of the gabbro was produced by pneumatolytic gases given off by the alkaline syenites intruded beneath the gabbro laccolith. The report of Fouquée and Lévy[11] is pertinent in this regard. They fused the powder of the "gefleckter" gabbro of Odegården, Norway, and the fused mass recrystallized as pyroxene and labradorite, showing that under ordinary conditions of pressure the slight amount of chlorine, occurring in the scapolite, is volatilized.

THE ORIGIN OF THE TITANIFEROUS IRON ORE DEPOSITS.

Titaniferous iron ore[12] occurs along the lower contact of the gabbro laccolith at several localities, other than the Pusey Iron Mine. A similar deposit occurs a quarter of a mile southwest of the Mine. A mile east of the Mine, ore is found associated with hornblendite. The hornblendite is similar to that containing segregations of graphite underlying the nephelite syenite north of Trooper Lake.

On the north shore of Big Pine Lake, three miles east of the Pusey Mine, nodules of iron ore, about the size of a bantam's egg, weather out of an amphibolite underlying the gabbro. The amphibolite is seen under the microscope to consist of blue hornblende, brown biotite, andesine, calcite, and iron ore. Calcite, in coarsely crystalline masses surrounded by biotite, forms twenty-five per cent. of the rock.

[10] The particular slide measured was unfortunate in having a large amount of magnetite present.

[11] Fouquée and Lévy, *Bull. Soc. Min. France*, Vol. 2 (1879), p. 113.

[12] For the chemical composition of the ore see F. D. Adams and A. E. Barlow, "Geology of the Haliburton and Bancroft Areas," Can. Geol. Surv., Memoir No. 6 (1910), pp. 353–354.

South of Laronde Creek, pegmatite dikes of quartz and feldspar cut a schistose pink syenite. The pegmatite dikes have inclusions of magnetite, in octahedral form, a foot or more in diameter.

It is the belief of the writer that the deposits just described were derived from the underlying intrusives by gaseous transfer. The evidence lies in the following facts:

1. The ore occurs in rocks whose textures are indicative of secondary alteration and recrystallization.

2. Alkaline syenites always occur below the iron ore deposits.

3. The overlying gabbro has been extensively scapolitized by chlorine derived from alkaline syenites intruded beneath the gabbro laccolith.

4. Minerals of pneumatolytic origin are associated with the ore; *e. g.*, scapolite, apatite, pyrrhotite, and blue hornblende.

5. The nephelite syenites have invariably enriched the lower contact of the gabbro in iron and magnesia and so produced scapolitic pyroxenites between the syenites and the gabbro.

6. The iron ore occurs as amœboid forms between the grains of the primary minerals of the gabbro and has reaction rims of blue hornblende and biotite with these older minerals.

7. The ore occurs, also, below the gabbro in amphibolites rich in calcite.

8. A logical source for the ore has been found in the granite pegmatites.

The evidence against the origin of these ores from the gabbro by magmatic differentiation under gravity is as follows:

1. The ore is separated from the gabbro by amphibolitic rocks containing calcite.

2. The ore occurs in amphibolites containing a large proportion of calcite.

3. There is no transition from ore to the country rock by decrease of magnetite, such as is shown in the ores of the Adirondack Region.[13]

[13] J. F. Kemp, U. S. G. S., 19th Ann. Report, Part III., p. 383.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

OCCURRENCE, GEOLOGY, AND ECONOMIC VALUE OF THE PITCHBLENDE DEPOSITS OF GILPIN COUNTY, COLORADO.

As my friend Mr. Alsdorf in a recent number of ECONOMIC GEOLOGY[1] has quoted at some length from a preliminary paper by me on the pitchblende deposits of that region, I wish to discuss his paper briefly, in the light particularly of the broader relations of the ores in that portion of Colorado.

Mr. Alsdorf and the writer are in accord in attributing the deposition of the pitchblende to solutions emanating from the same source or sources as certain of the Tertiary intrusive rocks. In this we both differ from Mr. Forbes Rickard[2] who associates the pitchblende mineralization genetically with earlier granitic intrusive rocks. The divergence of opinion between Mr. Alsdorf and the writer has to do with the precise sequence of events within the general period of Tertiary mineralization, and unfortunately field evidence is not sufficient to finally settle the points at issue. Mr. Alsdorf has had better opportunities than the writer to study the structural relations of various veins exposed in the pitchblende mines, most of these mines being closed at the time the writer's field studies were made. The points which will be made in this

[1] ECONOMIC GEOLOGY, XI., pp. 266–275, 1915.

[2] Rickard, Forbes, "Pitchblende from Quartz Hill, Gilpin County, Colo.," *Min. and Sci. Press*, June 7, 1913, pp. 851–856.

discussion rest therefore mainly upon comprehensive studies of the ores and rocks of Gilpin County and adjacent portions of Boulder and Clear Creek counties, and upon detailed studies of an unusually fine collection of rich pitchblende ores loaned to the United States Bureau of Mines by Mr. Forbes Rickard, and by that bureau loaned to the writer for study. The principal points to which attention is directed are as follows:

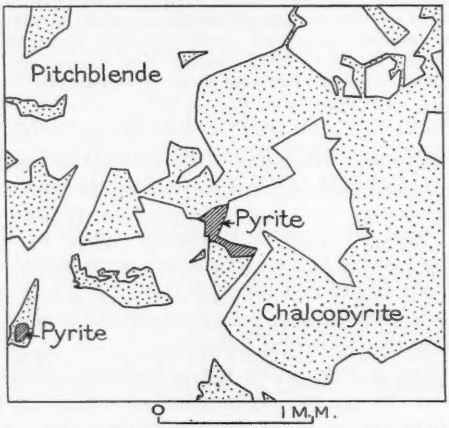

FIG. 47. Camera lucida drawing of polished surface of pitchblende ore from the Wood mine, Central City, Colo., showing contemporaneous intergrowth of pitchblende chalcopyrite and pyrite.

1. In all the numerous surface and underground exposures in this region there have not been found, in spite of careful search, any localities where the mutual age relations between the two types of Tertiary intrusive rocks—bostonites and monzonites—were shown.

2. No evidences were found by the writer or by his collaborator, Mr. J. M. Hill, of diversity in age among the bostonites, as postulated by Mr. Alsdorf. Moreover, the genetic relationship intimated by Mr. Alsdorf between two bostonite dikes of Quartz Hill and the pitchblende deposits, is not supported by the broader

geologic relations, which show that the bostonites are widespread outside the Quartz Hill pitchblende area, and also conversely that pitchblende occurs in the Jo Reynolds mine near Lawson not in known proximity to bostonite.

FIG. 48. Shows different part of specimen illustrated in Fig. 48.

3. It has been established beyond reasonable question, as will be fully set forth in the forthcoming final report on this region,[3] that the main sulphide mineralization which produced the gold-silver ores of the region was later than at least some of the bostonites and monzonites, and that this mineralization was dual in character, ores predominantly pyrite and chalcopyrite having been in many localities brecciated, and the interspaces of the breccia

[3] Bastin, E. S., and Hill, J. M., "Economic Geology of Gilpin County and adjacent portions of Clear Creek and Boulder Counties, including portions of the Central City quadrangle," Prof. Paper 94, U. S. Geol. Survey.

filled with ore carrying principally galena and sphalerite with subordinate chalcopyrite and pyrite.

4. Microscopic studies of a large number of specimens of the richest pitchblende ores all agree in showing that much of the pitchblende is intimately intergrown with pyrite and chalcopyrite in fashions shown in Figs. 47 and 48, that are indicative of nearly

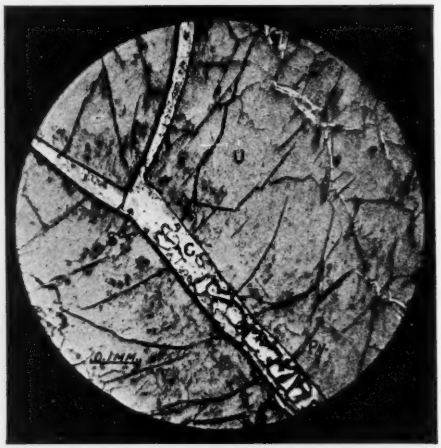

FIG. 49. Uraninite or pitchblende traversed by veinlet of pyrite (*Py*), sphalerite (*S*), and chalcopyrite (*C*). Microphotograph of polished surface of ore from German-Belcher mine.

simultaneous crystallization of the component minerals. On the other hand, fractured or brecciated pitchblende has been cemented by galena, sphalerite, pyrite and chalcopyrite in the fashion shown in Figs. 49 and 50.

5. It is possible that the pyrite and chalcopyrite contemporaneously intergrown with the pitchblende belong to a period of mineralization earlier than the common pyrite chalcopyrite ores of the district, but no evidence of this has been found by the writer. Mr. Alsdorf, though expressing a conviction that the pitchblende

ores are older, has not presented specific evidence in support of his belief.

6. For the present, and awaiting the uncovering of further field evidence, the writer prefers to adhere to the view at once simplest and most consistent with the broader relations of the

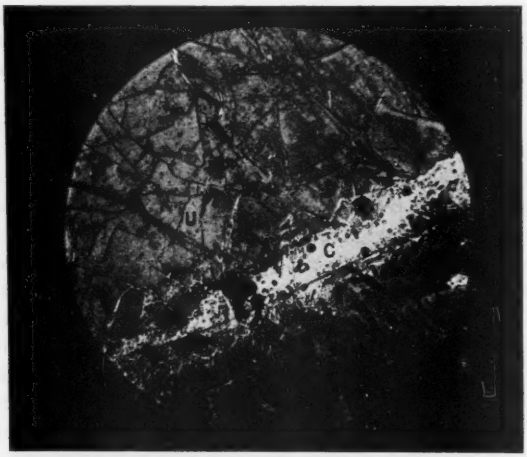

FIG. 50. Pitchblende (*U*) fractured and brecciated and the interspaces filled with ore (*C*) composed mainly of chalcopyrite with some galena, pyrite and sphalerite. Microphotograph of polished surface of ore from German-Belcher mine.

ores of the region, *i. e.*, that the pitchblende ores are a local variation of the widespread pyrite-chalcopyrite mineralization characteristic of this region, and are of the same order as other local variations observed in the same region, notably the presence of enargite in the pyritic veins of one locality, and of rhodochrosite in the galena-sphalerite veins of another locality.

EDSON S. BASTIN.

WASHINGTON, D. C.,
August 17, 1916.

Sir: On January 27 I wrote a letter on the subject of macroscopic intergrowths of dissimilar sulphide minerals which appears in No. 4, Vol. XI., for the month of June just to hand. In some mysterious way two lines of what I wrote have been cut out and two others substituted, making absolute nonsense of my last sentence, which is the kernel of the whole communication.

What I wrote was: "The outlines of both minerals (galena and bornite) being absolutely clean-cut, and the surfaces of both untarnished, there would appear to be no probability of secondary alteration of either, more especially taking into account that the two minerals are so dissimilar in chemical composition, the only element common to them both being sulphur." Since the *Mineralogical Magazine* may perhaps not be readily accessible to the majority of your readers, I may perhaps add that the macroscopic crystallographic intergrowths referred to take the form of small nodules embedded in a mass composed chiefly, say to the extent of nine tenths, of dazzlingly white crystallized wollastonite, the remaining one tenth being a small amount of garnet (andradite in yellow-brown dodecahedra) and still smaller amounts of bornite, chalcopyrite and opaque white opal, the two former in rounded grains and imperfect crystals, the latter in veinlets obviously of secondary origin. Under such circumstances any secondary alteration of galena into bornite or vice versa would appear to be inconceivable, and one is forced to the conclusion that both minerals are contemporaneous with the formation of the enclosing rock-mass, and that they crystallized simultaneously from the magma.

HENRY COLLINS.

CUEVA DE LA MORA,
VALDELAMUSA, HUELVA, SPAIN,
September 1, 1916.

Sir: In Vol. XI., No. 1, of your journal appears an article by Mr. D. C. Wysor, entitled, "Aluminium Hydrates in the Arkansas Bauxite Deposits." In this article the author draws certain conclusions that might conceivably be correct; as these conclusions do not appear to receive any support from the evidence placed

before the reader, and are at variance with the views held by other writers on the same subject, it seems desirable to examine them in some detail.

The author tabulates several analyses of Arkansas bauxites (Table IV.) and deduces therefrom that with one exception (no. 19) these bauxites (using the term in its commercial and petrographical meanings, which happen to be identical) are mixtures of either gibbsite or diaspore with the dihydrate $Al_2O_3 \cdot 2H_2O$, the bauxite of Dana (Table VI.). The analyses can, however, be equally well interpreted as indicating mixtures of the trihydrate and monohydrate. Which is the more probable interpretation is a question of evidence.

In the first place the author's deductions are to a certain extent vitiated by the fact that the alumina shown in the analyses was determined by difference, so that any lime, magnesia, or oxides of chromium, vanadium, etc., if present, have gone to increase the percentage of alumina. The latter constituent should surely be determined by direct weighing, if the analyses are to be used for mineralogical calculations.

Secondly, although the author has not applied the microscope to the study of his bauxites, he is probably correct, judging from the work of Professor Lacroix, in his assumption (p. 43) that "for all practical purposes we may consider them amorphous." But if this assumption be correct, it follows that the bauxites of Arkansas can contain neither gibbsite nor diaspore, both of which are well crystallized minerals with definite optical characters: instead, these bauxites probably consist of a mixture of colloidal hydrates, as has been suggested by Lacroix in the case of the amorphous bauxites of France.

Well-crystallized gibbsite is of course very commonly found in bauxites (*e. g.*, in India and French Guinea), but I am not aware that anyone has ever seen in bauxite (or laterite) a crystalline flake with the properties of diaspore. Some authors have assumed the presence of diaspore, but they were probably thinking of a compound of the chemical composition $Al_2O_3 \cdot H_2O$, rather than of a definite crystalline mineral.

It seems certain that in addition to the crystalline mineral gibbsite ($Al_2O_3 \cdot 3H_2O$), bauxites may contain amorphous and presumably colloidal aluminium hydrates of the composition $Al_2O_3 \cdot 3H_2O$ and $Al_2O_3 \cdot H_2O$; and the facts given in Mr. Wysor's paper may be interpreted as confirming the existence of these two amorphous hydrates, assuming that the bauxites are truly amorphous.

But no evidence has yet been adduced by anyone, as far as I am aware, indicating the existence of a dihydrate, either crystalline or colloidal. Mr. Wysor's analyses do not provide such evidence. Accepting Lacroix' determination that the bauxites of Arkansas are amorphous, analysis 19 of Table IV. indicates the existence of amorphous $Al_2O_3 \cdot 3H_2O$, not of gibbsite, and analysis 28 indicates the existence of amorphous $Al_2O_3 \cdot H_2O$, not of diaspore. All the intermediate analyses can be interpreted as indicative of admixtures of the tri- and mono-hydrates. Amorphous $Al_2O_3 \cdot 2H_2O$, if present, could not be detected from these analyses and at present it seems necessary to agree that no one has produced a shred of evidence to prove the existence in bauxite of a compound of the composition $Al_2O_3 \cdot 2H_2O$, either crystalline or amorphous. Further, it seems necessary to agree with Professor Lacroix and Sir Thomas Holland, the writers quoted by Mr. Wysor, that bauxite is a mixture of substances, *i. e.*, a rock, and not a mineral; indeed, the term bauxite should be omitted from all future text-books of mineralogy as the name of a mineral species, and recognition should be given to the fact that bauxite is a true rock. Should the existence of a natural substance of the composition $Al_2O_3 \cdot 2H_2O$ ever be proved it will not be entitled to the name bauxite, because the original material from Baux proves to be a rock.

In view of the above it seems probable that the Arkansas bauxites do not contain either gibbsite or diaspore, whilst no evidence is forthcoming justifying a belief in the existence of a natural dihydrate of alumina.

Consequently the author's third conclusion (p. 50), which relates to the order of formation of constituents, two of which are

probably absent, can have no meaning. It should further be noted that the paper does not contain any discussion of or facts relative to the second portion of the conclusion.

Coming now to minor matters attention should be directed to the assumption that titania exists in bauxites as ilmenite. It may be the case for the Arkansas bauxites, but if so the fact should be definitely verifiable by chemical and microscopical methods. Many Indian bauxites showing much higher amounts of titania than those from Arkansas do not, under the microscope, reveal any substance suggesting ilmenite. Lacroix has found a similar state of affairs in the bauxites of French Guinea and deduces the probability of the existence of an amorphous or colloidal hydrate of titania, and at present it seems reasonable to accept this view, although the microscope does not reveal the separate existence of this substance. This would, however, be anticipated, for the various colloidal substances (aluminium and titanium hydrates and hydrated aluminium silicates) would tend to occur in intimate admixture. Should the titania of the Arkansas bauxites be present as a colloidal hydrate and not as ilmenite then considerable changes would be necessary in Mr. Wysor's mineralogical calculations.

In his mineralogical calculations the author supposes that the silica is present as kaolinite. If one accept the view that the term kaolinite should be reserved for the crystalline forms of $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$, and the term lithomarge utilized for the amorphous forms of the same substance (sometimes more highly hydrated),[1] then since the Arkansas bauxites are amorphous, the term lithomarge should be substituted for kaolin; this change would not, of course, affect the calculations.

On p. 49 the author deduces the existence of a higher hydrate of alumina than the trihydrate. Would it not be just as reasonable to suppose that the iron oxide may be present as a more highly hydrated form than limonite, the aluminium silicate as a more highly hydrated form than kaolinite, and that the balance of water still left is partly hygroscopic and partly indicative of

[1] *Geological Magazine*, 1911, p. 511, and *Geol. Mag.*, 1915, p. 31.

an error in the determination of the alumina (which, it should be remembered, has been determined by difference)?

It will be noticed that a certain portion of my criticism of Mr. Wysor's paper is based on the assumption that the terms gibbsite and diaspore should be reserved for the crystalline forms of the respective aluminium hydrates. This is, of course, touching on a large subject. Professor Lacroix has reviewed the names that have been suggested for the colloidal aluminium hydrates, adopting the term alumogel proposed by M. Pauls;[2] and E. T. Wherry[3] has proposed that the amorphous or colloidal forms of crystalline minerals should be designated by the name of the corresponding crystalline mineral with the prefix k. According to this plan the amorphous tri- and mono-hydrates of aluminium would be designated k-gibbsite and k-diaspore respectively. This question of the nomenclature of colloidal forms of crystalline minerals has yet to be threshed out.

But my chief criticism is not dependent on the question discussed in the preceding paragraph. The point is that the author has not produced any reason for believing in the presence in the Arkansas bauxites of a compound of the formula $Al_2O_3 \cdot 2H_2O$.

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[2] *Geol. Mag.*, 1915, p. 33, and *Nouvelles Archives du Musée*, ser. v., tome v., p. 328, 1914.

[3] *Centralblatt für Min. Geol. u. Pal.*, 1913, p. 518. Dr. Wherry gives some examples of the crystalline and colloidal forms of the same composition: amongst these he gives psilomelane as the colloidal form of manganite, terming it k-manganite. It is, however, really the colloidal form of hollandite, *i. e.*, k-hollandite. A still more unfortunate example is k-bauxite, $Al_2O_3 \cdot 2H_2O$, regarded presumably as the colloidal form (not known to exist) of a hypothetical crystalline mineral of the same formula (also not known to exist).

REVIEWS

Microscopical Determination of the Opaque Minerals. By JOSEPH MURDOCH. 165 pp., colored frontispiece, 9 figures. New York, John Wiley & Sons, 1916.

This volume will be accepted by most American students of ore deposits with a grateful alacrity born of a very personal realization of the need of such a systematic study. Dr. Murdoch's record of the effect of a large number of reagents on the microscopic appearance of 186 distinct minerals (mostly opaque) is not a compilation but is mainly a statement of pioneer observations, and as such is entitled to special commendation. Probably no one understands better than the author himself that he has "started something" rather than finished his task, and that he has driven and garnished somewhat the pegs upon which a fund of information gathered by many workers present and future will be hung.

The criticisms and suggestions that follow are offered in the fullest appreciation of the difficulties of Dr. Murdoch's task, and of the high value of his accomplishment, in the hope that some of them may increase the usefulness of his work.

Following the preface by Prof. L. C. Graton, the introductory chapter is devoted to a generous summary of the quite meager results of earlier writers in this field, and to a statement of the scope of Murdoch's own work. A scant five pages is devoted to the methods of the preparation of polished specimens in use in the Harvard laboratories. The struggles of a number of us with this provoking and highly important phase of the work place us in the Missourian attitude toward the statement that "an average specimen may be polished in 6 or 7 minutes," and in many studies rather more delicacy of manipulation than is outlined by Murdoch appears to be necessary for satisfactory results. It is frequently necessary and usually desirable to guard against coarse abrasive dust by conducting the polishing in a separate room from the grinding, or under a glass-topped cover. For the final polishing the rouge must be ground for long periods of time and afterwards carefully water floated, and must be applied to the specimen on a wheel coated with a fine-textured cloth, such as fine linen. No doubt Dr. Laney, Professor Tolman and others of much experience in the preparation of polished specimens will be glad to contribute directly or indirectly to a useful elaboration, in a later edition, of this important phase of the subject.

In the sections devoted to "Examination," "Magnification" and "Photographing" the simplest forms of optical apparatus applicable to these studies are briefly described. It is certainly desirable to emphasize the fact that expensive apparatus is not essential to the study of most polished sections of ores, but on the other hand a discussion of methods seems incomplete without at least a mention of the great utility for high-power observations, and especially for photographing, of the Leitz micro-metallograph now in use in so many laboratories.

The last half of the book is a key, very convenient in general plan, for the microscopic identification of the opaque minerals. The first steps in running down a mineral in this key are based upon color and hardness; the later steps upon micro-chemical tests. The step that will probably present most practical difficulty to users of the volume is the classification of the many minerals that appear white under the microscope into sub-groups based on tint, as "creamy white," "pinkish white," "grayish white," etc., this classification being effected by comparison with galena as a standard of whiteness. If such a basis of classification is necessary, galena is probably a happy choice as a standard, since it is easily available to everyone and does not tarnish quickly after polishing. Where it is not a component of the ore under examination the bringing of an unknown mineral into juxtaposition with galena for color comparison is likely to prove a time-consuming and often a difficult manipulation. Without a close study of the matter, the suggestion is tentatively offered that "streak" might be used instead of slight differences in whiteness at this point in the key. The streak of most metallic minerals can very readily be determined under low powers of the microscope by scratching with a fine needle, and with little more damage to the specimen than that inflicted by determining the hardness and by treating with strong reagents. It is a test scarcely made use of at all in Dr. Murdoch's scheme, but one which the reviewer has found of the greatest assistance. Pricking with the point of a fine needle may show that a mineral is sectile and may be of material aid in identifying such minerals as argentite.

The method recommended for applying reagents by a capillary tube is unquestionably the best in many cases, but an alternative that is sometimes preferable is to apply the reagent with a strip of soft white blotting paper about 2 inches long and ½ inch wide, usually slightly tapered at one end. The tapered end is moistened with the reagent and the part of the specimen to be tested is swabbed lightly with it. The progress of the tarnishing can be closely observed under the microscope and quickly checked by blotting with the dry end of the strip, or in the case of strong reagents, by washing. This method is particularly useful in preparing

the surface for drawing or photographing, since the possibility of quickly checking and if need be of renewing the reaction permits just the right amount of tarnish to be secured. Blotting paper will not injure the finish of the specimen.

The microchemical reagents employed by Dr. Murdoch are the following: HNO_3 (concentrated and 1 to 1), KCN, HCl (concentrated and 1 to 1), Aqua Regia, $FeCl_3$ (20 per cent.), KOH (concentrated), NaOH (concentrated), NH_4OH (28 per cent.), $(NH_4)S$, Iodine (alcoholic solution), $K_3Fe(CN)_6$ (20 per cent.), $K_4Fe(CN)_6$ (20 per cent.), H_2SO_4 (dilute or concentrated), $AgNO_3$ (3 per cent. and 10 per cent.) and $KClO_3$ (saturated). These reagents are used primarily for identification. For the benefit of the uninitiated it may be well to point out that microchemical reagents are useful in the study of ores not only as an aid in identification, but also as a means of producing or accentuating contrasts between certain minerals so as to bring out structures not otherwise clear in preparation for detailed study, drawing, or photographing. For such purposes it is commonly best to use reagents of such strength or character that they attack the minerals slowly, so that the reaction can be checked when desired, and its effect quickly obliterated by brief repolishing. Two reagents not on Dr. Murdoch's list have been found particularly useful by the reviewer: The first is a saturated solution of mercuric chloride. This is useful to bring out the contrast between the common base metal sulphides and silver sulphides and sulpho salts associated with them, for it attacks the former slowly or not at all, while rapidly producing a brown tarnish on argentite, polybasite and pyrargyrite. It is useful further in contrasting pyrargyrite and polybasite in mixtures of the two, for on short treatment pyrargyrite tarnishes pale brownish yellow, and polybasite a pronounced brown. The second reagent is commercial hydrogen peroxide which slowly tarnishes galena brown but affects few other minerals. The reaction is accelerated if the peroxide is applied hot. This reagent is particularly useful in differentiating galena from argentite, polybasite, pyrargyrite, and the other silver minerals with which it is frequently associated, the silver minerals being unaffected. By its use Dr. Laney and the reviewer have determined that a mineral associated with galena in the Tonopah ores and indistinguishable from it on freshly polished surfaces and with the ordinary reagents, is a new species, probably a lead-silver sulphide.

Finally while the value of the reflecting microscope as an instrument for the determination of mineral species is tremendously enhanced by Dr. Murdoch's work, it is appropriate to emphasize the necessity, for the present at least, of reinforcing the microscopic determinations whenever possible by chemical and crystallographic studies. It is frequently if not

usually possible to isolate small amounts of a mineral from the surface of the polished section and to observe, under a lens if need be, its cleavage, streak, etc., and to apply to it simple blow-pipe or wet chemical tests. Frequently also a mineral in a polished surface may be traced to a small vug where its crystal form can be noted.

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WASHINGTON, D. C.,
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